DISTRIBUTION OF LARVAL AND JUVENILE RED KING CRABS (*PARALITHODES CAMTSCHATICA*) IN BRISTOL BAY

by

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CLARIFICATION

All references to “sea onion” in this volume refer to the sea squirt (an ascidian). References to asteroids refer to sea stars.

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ACKNOWLEDGEMENTS

This study was originally conceived by David Armstrong and some of the participants of the 1982 North Aleutian Shelf synthesis meetings. NOAA/NOS scientists including Lyman Thorsteinson and Steven Zimmerman further defined the research needs that led to this program. Al 1 an Vogel was principal investigator for the plankton component, Paul Fishman was principal investigator for the epibenthic and fisheries component, and David Armstrong was a co-investigator on all aspects of the species biology. Gregory McMurray was responsible for the ancillary physical data and overall project management. Discussions between the authors and with NOAA/NOS advisors Lyman Thorsteinson and Jawed Hameedi brought the project to its final scope and content. Discussions with Robert Cimberg, VTN, who worked in Izembek Lagoon during 1982, and Murray Hayes and Bob Otto, National Marine Fisheries Service, were also helpful for sampling strategy.-

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Laboratory and data analysis and report preparation were assisted by a number of people. Bill Kemp analyzed all of the sediment samples. Ron Simmons and Williey Knox were responsible for data entry and EDP software, respectively. Janet Armstrong helped with larval data analyses and graphics at the University of Washington and also collected additional zooplankton samples during another cruise. Susan Donin processed the words and Gary Austin drafted the figures. Robert Smith of Ecological Data Analysis assisted the community analysis of the epibenthic data.

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ABSTRACT

The goal of this study was to better define the relationship between larval distribution and juvenile recruitment of red king crab (*Paralithodes camtschatica*) in the Bristol Bay region. Cruises during April-May, June and September 1983 collected larvae with bongo net tows, and juveniles and adults with trynet trawls and rock dredge hauls. Ancillary physical and biological measurements were made and tested for correlations with the observed larval and juvenile distributions.

The results of the larval sampling demonstrated a very weak 1983 cohort. Hatch apparently occurred during the last week of April and the first week of May, later than recorded in most years. The distribution of larval red king crab in Bristol Bay was characterized by a density maximum near the middle of the bay, and generally low density along the North Aleutian Shelf (NAS) as compared to earlier years. Larvae were not found in Togiak or Kvichak Bays. Vertically stratified samples gave strong evidence of diel vertical migration by red king crab larvae. The distribution of larval red king crab observed during 1983 is generally consistent with the concept of transport northeast along the North Aleutian Shelf and northwest in the upper part of Bristol Bay. It is not known whether longshore NAS currents may persist all the way into Kvichak Bay, but the occurrence of 1983 young-of-the-year crabs suggest this since no larvae were observed there. It is not clear whether the location of the larval density maximum was a result of offshore transport from the NAS or release by ovigerous females observed in the middle of Bristol Bay.

The results of juvenile sampling demonstrated the presence of crabs younger than three years generally inshore of the 50 m isobath. Age 0+ crabs (1982 cohort) were found off Ports Moller and Heiden and in Togiak and Kvichak Bays, both during April-May and June. Young-of-the-year crabs (1983 cohort) were found off Ports Moller and Heiden and in

Kvichak Bay during September. The distribution of juvenile crabs supports the hypothesis of "refuge" habitat. The results of statistical analyses indicate that biological parameters correlated better with the apparent juvenile crab distributions than did physical parameters. Strong, positive correlations were found between age 0+ to 2 juvenile crabs and sea urchin (Strongylocentrotus droehbachiensis) biomass and between young-of-the-year crabs and tube-building polychaete worm biomass. Older juvenile crab distributions correlated positively with sea onion (Boltenia ovifera) biomass.

The physiological and ecological characteristics of red king crab larvae make this life history stage the most susceptible to oil and gas pollution. The natural variability being documented in red king crab stocks indicates that vulnerability of the fishery to oil and gas could be greatly increased during years of extremely low recruitment such as 1983.

SECTION 1.0

INTRODUCTION

The red king crab fisheries of the southeastern Bering Sea (SEBS) have, in recent history, been the richest fished by U.S. fleets with an ex-vessel value of $169 million in 1980 (Eaton 1980; NOAA 1981; Otto, et al. 1980a; Otto 1981). Populations in 1978 to 1980 were the highest estimated by the National Marine Fisheries Service (NMFS) in over 10 years (Otto 1981; Otto, et al. 1982) and caused an expansion in fishing effort and the fleet working the SEBS. However, the commercial fishery suffered depressed landings of red king crab in 1981 and 1982. Landings declined from 131 x 10^6 lb in 1980 to about 35 x 10^6 lb in 1981 (INPFC 1982), and the fishery was closed at about 3.5 x 10^6 lb in 1982 (M. Hayes, NMFS, Seattle, pers. communication). Such severe reductions in landings are in accord with NMFS predictions of decreased abundance (a five-fold decrease from 1979 'to 1982; Otto, et al. 1982), and reflect substantial, but unexplained, variation in success of year classes. Further depression of fishable stocks and mature females and subadults have been so severe that NMFS and the Alaska Department of Fish and Game (ADF&G) recommended that the 1983 season for Bristol Bay not be opened so that the population might recover (M. Hayes, NMFS, Seattle, pers. communication). Exact causes underlying such pronounced fluctuations in abundance of this and other crab species are not known, but numerous hypotheses have been advanced that advocate both biotic and abiotic factors (see reviews by Hayes 1983, Armstrong 1983).

Oil and gas development on the outer continental shelf of Alaska is scheduled to begin in the near future and proceed over the next decade. The Minerals Management Service (MMS) has charged the Outer Continental Shelf Environmental Assessment Program (OCSEAP) with initiation of research contracts designed to elucidate biological and physical/chemical processes in the areas of proposed oil and gas development. The results of many research projects have been summarized in workshops sponsored by OCSEAP at which oil impact scenarios were considered and the vulnerability of species gauged. Crab biology was reviewed for the St. George Basin by Curl and Manen (1982), and for the North Aleutian Shelf (NAS) by Armstrong, et al. (1983a).

A notable example of research initiated to better understand the life history and general biology of a species is that recently and presently focused on red king crab along the NAS and throughout Bristol Bay. Despite extensive literature on the species (e.g., Armstrong, et al. 1983b; Reeves and Marasco 1980) much is unknown regarding early life history in the SEBS. Armstrong (1983) listed research needs that included studies of temporal and spatial larval population dynamics, the relationship of larval hatch and transport to female stocks, and location of megalopae at metamorphosis and substrate types on which survival of O+ to 1+ juveniles is greatest. Armstrong et al. (1983b) advanced hypotheses on hatching success and larval survival and metamorphosis that stated: 1) much of the female population of the SEBS may be superfluous to year class success because it occurred over the central shelf where either larval and/or O+ juvenile survival is very low; 2) the nearshore area of the NAS is critical for larval growth and survival; 3) larvae can be transported great, but variable, distances during pelagic growth; 4) survival of young benthic instars is probably very dependent on settlement onto protective “refuge” substrates; and 5) that such substrates (shell, cobble, invertebrate aggregates) are patchy along the nearshore NAS.

Based on recent work by Armstrong, et al. (1981a, 1983b) and research priorities identified at the 1982 North Aleutian Shelf synthesis meeting (Armstrong, et al. 1983a), the program discussed in this report was initiated by OCSEAP in 1983 to provide specific information on early life-history of red king crab in Bristol Bay.

1.1 Study Objectives

The goal of the present study is to provide sufficient information on larval and juvenile red king crab distributions and associated environmental variables to reasonably describe the potential effects of oil and gas development on the crab population and its fishery. Specific objectives of the program are to:

1) collect and measure larval red king crabs, identify them to growth stage and assess their apparent spatial distributions in Bristol Bay;

2) determine the spatial distribution and changes in individual size of juvenile red king crabs (<60 mm carapace width) in the study area;

3) identify correlations between the physical and biological environment of the Bristol Bay vicinity and the observed distribution and relative abundance of larval and juvenile red king crabs; and

4) contribute to an overall understanding of OCS oil and gas development effects on red king crab populations and fisheries for this species.

1.2 Description of the Study Area

The study area, which includes Bristol Bay and a portion of the southeastern Bering Sea (SEBS) and the North Aleutian Shelf (NAS), is indicated in Figure 1.2-1. The area covers the area north and west of the Alaska Peninsula and Unimak Island west to 165°W and south and east of a line running from 165°W, 57°45'N to Cape Newenham. This study was originally designated "North Aleutian Basin"; it has been retitled "Bristol Bay" to more accurately indicate the focus of the study.

The Bristol Bay area is shallow with depths of over 100 m limited to a small area in the extreme southwest of the study area, just north of the North Aleutian Shelf. Approximately one half of the area is shallower

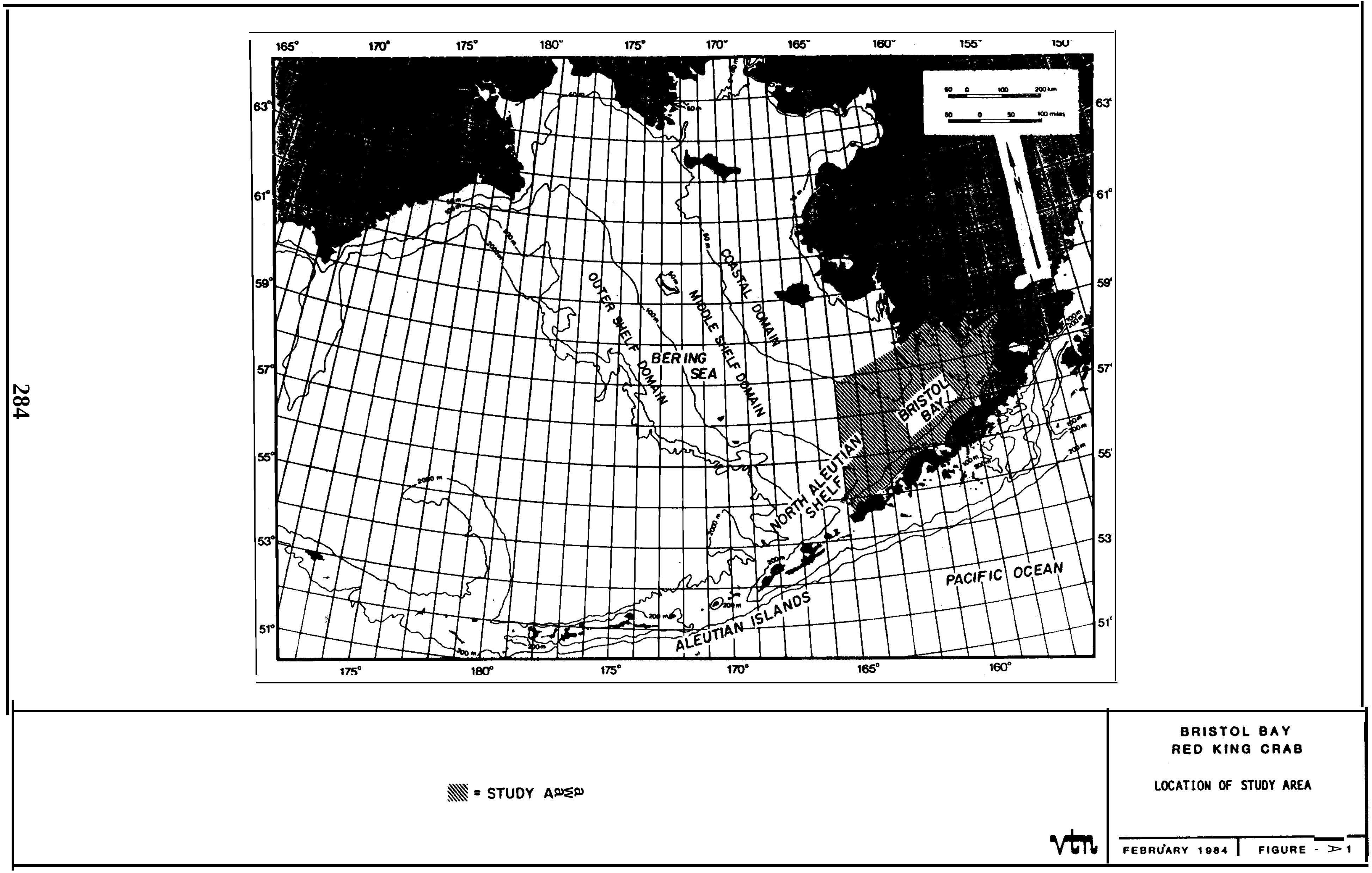


Figure 1.2-1 Location of study area.

than 50 m. The oceanography of the SEBS and NAS vicinities has recently been summarized in Hood and Calder (1981); hydrography and circulation are reviewed by Kinder and Schumacher (1981a, b). The sedimentary environment and substrates in the area have been summarized by Sharma (1979).

1.3 Life History and General Biology of the Red King Crab

1.3.1 Distribution and Abundance: Benthic Juveniles and Adults

Red king crab (*Paralithodes camtschatica*) are widely distributed from the Sea of Japan in the western Pacific through the Kuril Islands to the Kamchatka Peninsula, across to the southeastern Bering Sea and as far south as British Columbia in the eastern Pacific (Marukawa 1933; Vinogradov 1946; Weber 1967). The species is rather uncommon north of latitude 57″N and is characterized as part of the subarctic-boreal faunistic system (Neyman 1963, 1969). Further, Russian scientists rarely find it in large numbers north of the Anadyr faunistic barrier (a line from the Anadyr River to St. Matthew Island), in marked contrast to the blue king crab which ranges farther north and seems to inhabit colder water (Slizkin 1973).

In the SEBS where a major fishery is centered, information on distribution and abundance of red king crab in these shelf areas is more comprehensive than for any other decapod fished by U.S. fleets. For more than 12 years, the NMFS has conducted broadscale trawl surveys in the southeastern Bering Sea, and Otto (1981) provides a history of information gathered by Japanese and Russian fleets during their participation in the fishery. A series of annual reports by the International North Pacific Fisheries Commission (INPFC) since the late 1950s provides a continuum of detailed data on king and also Tanner crab (*Chionoecetes* spp.) stocks in the southeastern Bering Sea as well as in other locations fished by member nations.

Data on distribution and abundance of red king crab are essential for predictions of potential oil and gas development impacts, particularly in regards to early life history stages which may be most susceptible to hydrocarbon toxicity (Armstrong, et al. 1983a,b). Distribution seems to be coupled, in part, to physical oceanographic domains which, for the SEBS shelf including Bristol Bay, are the coastal, middle and outer shelf domains that extend to about the 50 m, 100 m and 200 m isobaths, respectively (Kinder and Schumacher 1981a; Figure 1.2-1). Throughout this area red king crab are distributed somewhat in accord with sex and life history stage. In general, female and small male king crabs (<110 mm carapace length) are found closer to shore and somewhat east of large males (Otto, et al. 1980a,b, 1981). Very young juvenile red king crabs of o+ to 4+ age classes are rarely caught in nets throughout the NMFS survey area, even though the mesh used would retain animals as small as 30 mm. The implication is that juvenile crabs up to 60 mm in carapace length (about 3 years old; Weber 1967) are absent from the survey area and likely occur very nearshore along the North Aleutian Shelf or in eastern Bristol Bay. More precise information on this subject is a major objective of the present study.

Abundance estimates of red king crab have fluctuated between years in the last decade and cycles of high to low abundance may occur in this species' populations as have also been observed for the Dungeness crab, Cancer magister (Armstrong 1983; Botsford and Wickham 1978). Landings from the Kodiak king crab fishery have also fluctuated widely from 94 x 10^6 lb in 1965 to a low of 10 x 10^6 lb in 1981, and have remained around 14 x 10^6 lb to the present (NOAA 1981). Poor recruitment is cited as the cause for this pronounced decline in abundance. In the southeastern Bering Sea, crabs were in moderate abundance in 1953, "increased in abundance to 1959, fell between 1964-70, and then increased through 1979 (Otto 1981). However, abundance estimates for total (juvenile plus adult) male king crab in this area have declined from 181 million animals in 1977 to 129 million in 1982 (Otto, et al. 1982). Most importantly, estimates of sublegal males one to two years from entering the fishery have declined nearly threefold from 64 to 17 million, leading to predictions of several consecutive years of poor fisheries. Abundance estimates of legal male crabs dropped from over 45 million animals in 1979 to about five million in late 1982; (M. Hayes, NMFS, Seattle, pers. communication; Otto, et al. 1982) which has resulted in the severe reductions in commercial landings.

Change in abundance of king crab populations is an important biological factor considered later in discussing oil impacts. Cycles of abundance suggest that year class failure or success may be based on survival of critical life history stages such as larvae or young juveniles, likely in nearshore habitats. Instantaneous mortality rates of juvenile and sublegal, sexually mature crab are estimated to be low, about 0.10 yr^{-1} until entering the fishery (Balsiger 1976; Reeves and Marasco 1980). Consequently the magnitude of a future fisheries cohort is largely determined by the reproductive success and survival of larvae and young-of-the-year (O+ crab) in nursery areas. Vagaries of temperature, food supply and predator populations are factors probably affecting survival, but as yet are poorly studied. In addition, the number and location of spawning females may significantly influence larval survival and location of megalopae relative to optimal substrate at metamorphasis (Armstrong, et al. 1983b). Additional information on these topics are also important objectives of the present study. Female abundance and geographic location have shifted from high numbers nearshore off Unimak Island to Port Heiden in the late 1970s to very low abundance nearshore along the entire NAS, and a redistribution over the central shelf domain (Armstrong, et al. 1983b). Potential oil perturbations could add to natural pressures on larval and juvenile populations and further suppress stocks.

1.3.2 Reproduction

During late winter and early spring in the Gulf of Alaska, adult males apparently migrate from deeper, offshore areas to join females in shallow water for breeding around Kodiak Island (NOAA 1981; Powell, et al. 1974; Weber 1967) and it is suspected that such migratory behavior occurs in the southeastern Bering Sea as well. Eggs carried from the previous year hatch about April 1-20 (Armstrong, et al. 1983b; Haynes 1974; Weber 1967) and females soon undergo physiological changes leading to molt. By pheromone attraction (NOAA 1981) sexually mature males locate preecdysial females, embrace them for as long as 16 days, and mate just after the female molts (Powell, et al . 1974). The nearshore, shallow water habitat is apparently selected in part for warmer water temperatures and also perhaps greater food supplies. The average temperatures associated with sexually mature males and females are 1.5" and 4*c, respectively (NOAA 1981). Stinson (1975) correlated male and female abundance with temperature and, from NMFS survey data through 1975, located most sexually mature females inside a 4°C isotherm near-shore off Unimak Island and directly in front of Port Moller. Weber (1967) summarized data on temperature-related hatchout time and development, noting both regional and annual differences in larval appearance and rate of development attributable to temperature variations. Larval development time can double with a decrease of temperature from 10" to 5°C (Kurata 1960, 1961), and an average of 460 degree days (= cumulative average daily temperature) is required for development from hatch of egg to metamorphoses of megalops (Kurata 1961).

After molting, a female must be located and mated within five days for viable eggs to be produced. Males are larger than females in 97 percent of all mating pairs (Powell, et al. 1974), and insemination of larger females by smaller males results in reduced clutch size (egg number). Any combination of events through natural and fishery mortality and pollution that substantially reduce numbers of large males at some point in time could threaten the breeding potential of the species. Reeves and Marasco (1980) estimated that a male-female weight ratio of 1.7 is required for 100 percent copulation. This estimate is based, in part, on behavioral observations by Powell, et al. (1974). Below this value, decreasingly lighter males will have less success breeding large mature females. This relationship supports the observations of the 1982 NMFS survey cruise that found an unusually large number of barren female crabs in a year of very low male abundance. The relationship between spawners and eventual recruits for this species is unclear (Reeves and Marasco 1980).

Females carry eggs for up to 11 months as embryos develop through naupliar stages to prezoea (Marukawa 1933). This protracted developmental time makes eggs (during early cleavage) and later embryos susceptible to long-term benthic oil pollution, and should be considered in scenarios of oil mishaps and possible perturbations to larval populations. Again, gravid king crab females are aggregated nearshore in relatively shallow water along the North Aleutain Shelf, but such distribution is poorly studied to date.

1.3.3 Larval Biology

Time and Area of Hatch. Larvae are hatched nearshore (Armstrong, et al. 1983b; Haynes 1974), molt through four zoeal stages, each about three weeks (Armstrong, et al. 1983b; Marukawa 1933), spend two to four weeks as megalopae, and then metamorphose to first instars about late July to August (Armstrong, et al. 1983b; Kurata 1960; Weber 1967). Eggs normally begin to hatch in early April (Haynes 1974; INPFC 1960; Sato 1958), although female king crab may vary in time of hatch between widely separated populations from Unimak Island to Port Moller. Korolev (1968) summarized data collected by Soviet scientists for June 1959 along the North Aleutian Shelf. Over 95 percent of the female populations between 161°25′ to 165″10′W had spawned and carried new egg masses in June, while 90 percent of females east of 161°25'W (Port Moller and east) carried empty egg cases indicative of recent hatch, and only 10 percent carried new purple egg masses. Armstrong, et al. (1983b) have presented evidence that egg hatch is not synchronous along the NAS from Unimak Island to Cape Seniavin, and concluded that larvae emerge earlier in the southwest portion of the NAS range and later to the northeast, probably in accord with differences in water temperature.

Interannual timing of the onset of hatch and seasonal occurrence of pelagic larvae can vary by as much as 1.5 months. Japanese data (INPFC 1963, 1965) show that nearly 100 percent of gravid females sampled during 1960 carried "eyed" eggs (fully developed zoeae, hatch imminent) until May 10 and 50 percent carried empty egg cases by May 20-30. In 1963, eyed eggs were carried until April 20 and 50 percent had hatched by April 30. Larvae hatched late (mid-May) in 1976, but early in 1979 when most were already stage IV (SIV) by mid-June (Armstrong, et al. 1983b).

Horizontal transport of king crab larvae by currents is thought to move them significant distances from the origin of hatch, and implies to some authors that recruitment of juveniles to a given area might depend on larvae hatched elsewhere, including areas south of the Alaska Peninsula (Haynes 1974; Hebard 1959). Hebard (1959) calculated that larvae hatched at Amak Island could be transported over 95 km to the northeast and metamorphose at Port Moller based on a net current speed of 2 cm see-l. He further discussed possible transport of larvae from south of the Alaska Peninsula through Unimak and False Passes. Haynes (1974) adds credence to this supposition by showing a northerly dispersion of king crab. larvae off the southwest tip of Unimak Island, and a northeast shift in areas of larval abundance from Black Hills into Bristol Bay (May-July 1969 and 1970). This pattern may in part be due to inadequate spatial sampling. Armstrong, et al. (1983b) concluded that larvae could be transported over 200 km along the NAS based on the time required for development (3.5-4 months) and current speeds of about 2 cm sec^{-1} (Ki rider and Schumacher 1981b).

Growth. Temperature is considered one of the most crucial physical factors affecting survival and growth of 1 arvae. Kurata (1960, 1961) calculated that 460 degree-days were required to progress from hatch to metamorphosis. Lethal temperatures are those greater than 15°C or lower than 0.5-1.8°C (Kurata 1960). He found greatest survival of zoeae between 5-10"C and formulated an equation that relates developmental time to temperature. Time from egg-hatch to molt of stage I (S1) to stage II (S11) varies from 24 days at 2°C to nine days at 8°C (Kurata 1960). Severe climatological changes could account for large fluctuations in survival of a year-class and later recruitment to the fishery. Niebauer (1981) shows that the limit of ice in the southeastern Bering Sea (as a relative measure of water temperature) was several hundred kilometers farther south in 1976 than 1979 and actually extended to the Alaskan Peninsula near Black Hills. Both 1975 and 1976 were severely cold years and poor survival of larvae and juveniles then could account for low abundance of sublegal males five to six years later in 1981-82.

Growth of larvae is substantial during pelagic development with increases from about 200 mg dry weight as new S1 zoeae to over 1,200 mg as megalopae (Armstrong, et al. 1983b). Feeding habits and prey preference of larvae in the wild are unknown, but both zooplankton and centric diatoms have been found in guts of specimens from the NAS (D. Armstrong, unpublished data from June 1983). Paul, et al. (1979) studied the response of red king crab zoeae to food density and found that while several species of copepods were captured, the density required greatly exceeded natural densities as measured by integrative bongo tows. Paul and Paul (1980) studied the effect of temperature and starvation on subsequent ability to capture food, and found that red king crab zoeae held at 2" and 4°C without food for 84 hours were unable to capture prey when later presented. This result suggests that starvation may be caused by relatively short periods of low food abundance and is applicable to considerations of early zoeal ecology along the NAS.

1.3.4 Benthic Biology of Young Juveniles

Little is known of the distribution and abundance of young-of-the-year (0+) crabs and of subsequent instars through two years of age (1+) along the NAS and, in fact, throughout the southeastern Bering Sea; providing information on this life-history stage (stanza) is a major objective of the present project. Weber (1967) described shallow water ecology of young juveniles in Dutch Harbor that, along with descriptions of habitat occupied around Kodiak Island (Jewett and Powell 1981; Powell and Nickerson 1965) and in Kachemak Bay (Sundberg and Clausen 1979) has led to a hypothesis of strict habitat requirements for survival (Armstrong 1983; Armstrong, et al. 1983b). A working hypothesis in the beginning of the present study was that O+ juveniles require substrate that affords both refuge from predators and adequate food (e.g. shell, cobble, biological materials such as tube worms). The link between the location of megalops larvae at metamorphosis and appropriate bottom material was viewed as one critical determinant of year class strength.

Location of such refuge substrate and O+ to 1+ juveniles was found previously to be very difficult along the NAS. During a 1982 OCSEAP project to study feeding habits of small juvenile red king crab, almost no animals in this size range (about 5 to 25 mm carapace length) were found using nets, divers and underwater cameras (W. Pearson, Battelle NW Laboratories, pers. communication). The National Marine Fisheries Service has caught virtually no crab of this size in over a decade of extensive sampling (e.g. Otto, et al. 1982). Armstrong, et al. (1983b) attributed this to inappropriately large gear and little effort nearshore where they assumed this stage must be most common.

Growth rates of O+ and older juveniles have been studied and animals reach mean carapace lengths of about 11 mm, 35 mm, 60 mm and 80 mm at one, two, three and four years, respectively (Powell and Nickerson 1965; Weber 1967). Growth models for the species have been developed by McCaughran and Powell (1977), Reeves and Marasco (1980) and Weber (1967). Young-of-the-year molt from eight (Powell 1967) to 11 (Weber 1967) times in the first year. Such a high frequency of molting could make them particularly susceptible to nearshore oil pollution since ecdysis is the time of greatest sensitivity to toxicant stress (Armstrong, et al. 1976; Karinen 1981).

Juvenile crab in 2+ to 3+ age classes (entering their third through fourth year) form large aggregates called "pods" in the Gulf of Alaska (Powel 1 and Nickerson 1965). Podding behavior is probably based on chemosensory cues (subject to oil effects) and is thought to serve as protection from predators. It is not known if the same behavior occurs among juveniles of the North Aleutian Shelf.

Red king crab are sexually mature at about 95-100 mm carapace length for males (NOAA 1981; Weber 1967) and 85-90 mm for females in the Bering Sea (Weber 1967) or 93-122 mm in the Gulf of Alaska (Powell and Nickerson 1965). Animals are five to six years old at sexual maturity and males are therefore capable of breeding two to three years prior to entering the fishery at about eight years of age.

SECTION 2.0

METHODS

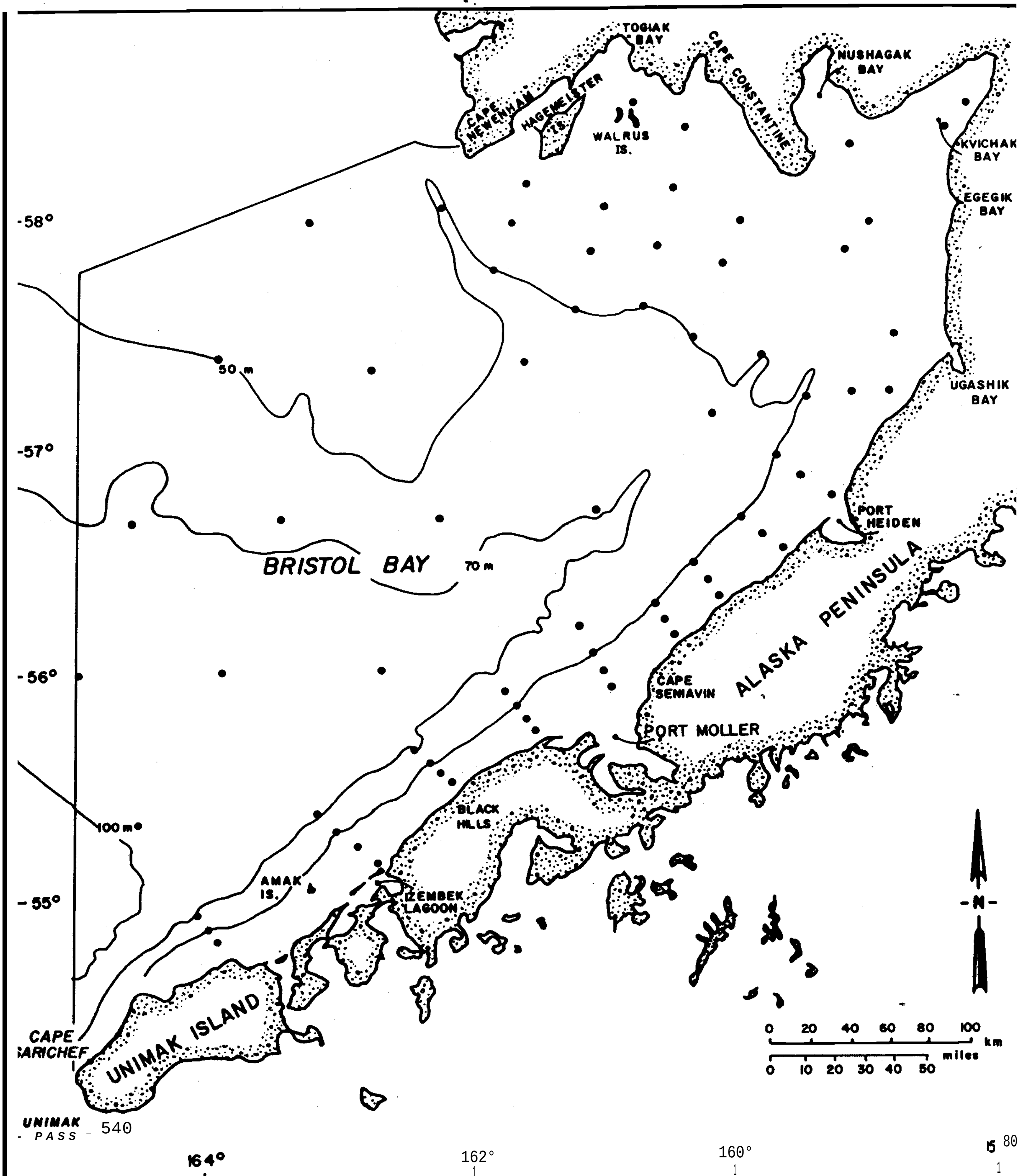
2.1 Field Methodology

2.1.1 Timing and Location of Sampling Effort

Three cruises were scheduled for this project during 1983: 18 April to 7 May (cruise 83-l); 2-17 June (cruise 83-3); and 9-23 September (cruise 83-5). In addition, opportunistic sampling for decapod larvae along the 50 m isobath from Port Moller to Unimak Island was conducted on 27 May 1983 during the Blue King and Korean Hair Crab cruise to the Pribilof Islands (cruise 83-2). The NOAA ship Miller Freeman was used for all cruises. The sampling locations for the three scheduled cruises are shown in Figures 2.1-1 through 2.1-3. The types of data collected and quantities are summarized in Table 2.1-1.

The sampling design originally consisted of 72 permanent stations, each to be sampled at least once during every cruise. Twelve of the stations were offshore at previously established NMFS crab fisheries survey locations (Otto, et al. 1982). The other 60 stations were arranged in 15 transects perpendicular to the shore with station bottom depths of 20, 30 and 50 or 70 m for each station in every transect.

The alpha-numeric station code (Figures 2.1-4 and 2.1-5) indicates the subarea (letters), transect number within the subarea (first digit), and the approximate bottom depth in meters (last two digits). Three of the transects occupied equivalent positions to those sampled by Armstrong during 1982 west of Black Hill to Cape Sarichef on Unimak Island. Two transects were similarly located off Port Moller. Five transects were located along the south side of Bristol Bay between Ports Moller and Heiden. Four more transects were located along the north shore out to Cape Newenham and one was located down the axis of Kvichak Bay.



● = SAMPLING STATION

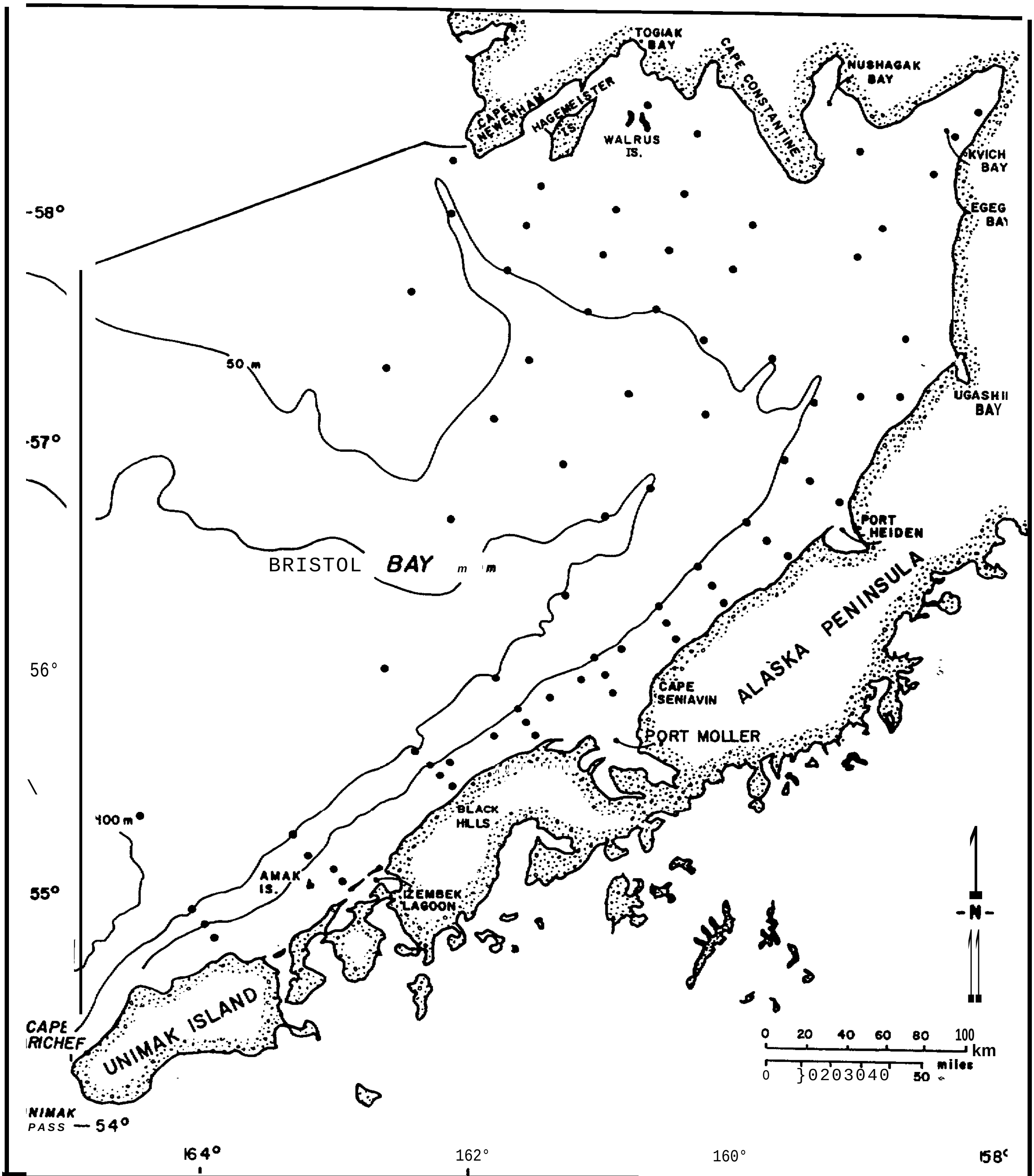
— : **STUDY** AREA BOUNDARY

BRISTOL BAY
RED KING CRAB

CRUISE 83-1
SAMPLING STATIONS

FEBRUARY 1964

FIGURE 2.1-1



● = SAMPLING STATION

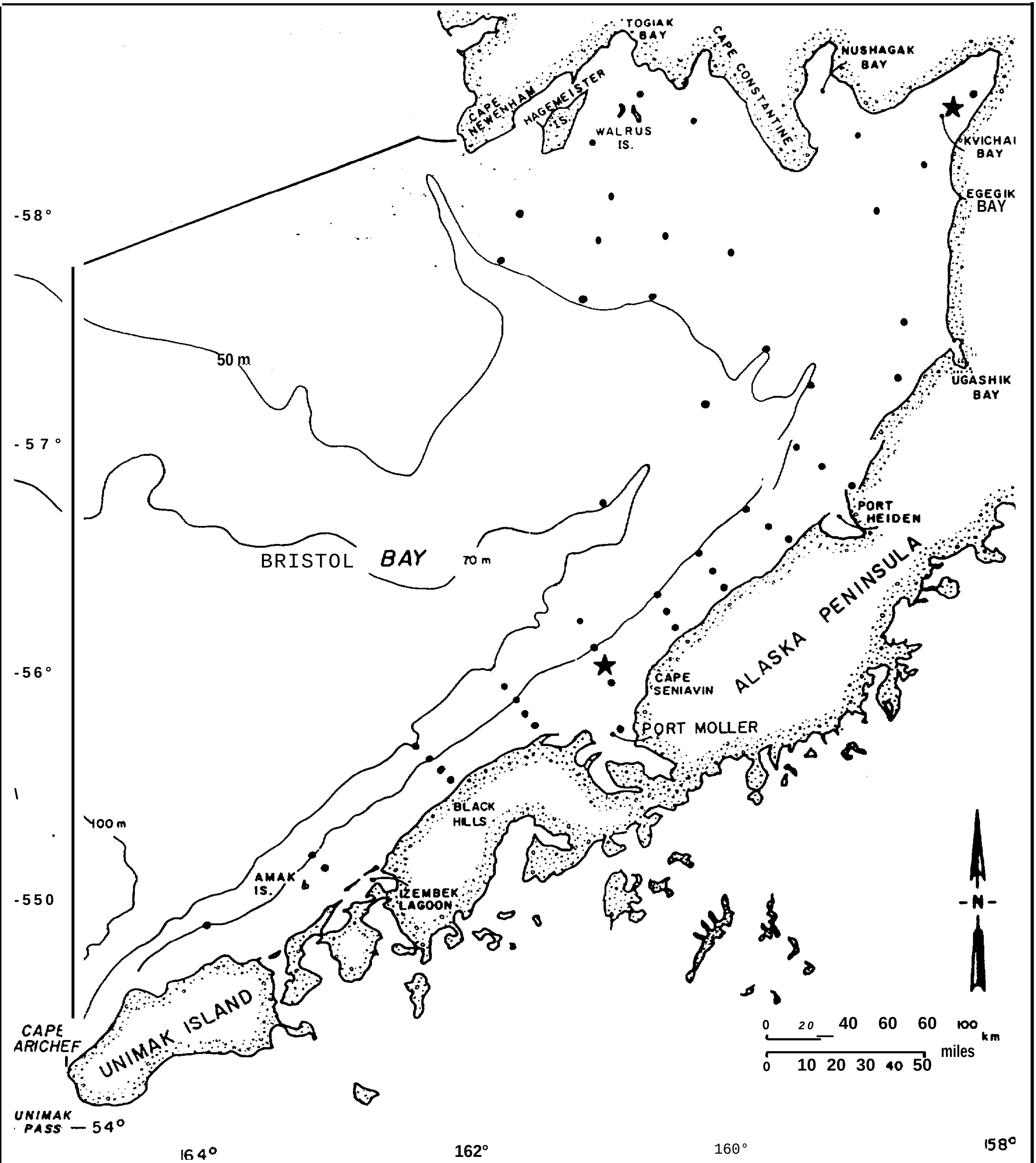
— = STUDY AREA BOUNDARY

BRISTOL BAY
RED KING CRAB

CRUISE 83-3
SAMPLING STATIONS

FEBRUARY 1984 | FIGURE 2.1-2

vtn



— = STUDY AREA BOUNDARY

• = SAMPLING STATION

★ = INTENSIVE SIDE SCAN SONAR SURVEY SITE

BRISTOL BAY
RED KING CRAB

CRUISE 83-5

SAMPLING STATIONS

FEBRUARY 1984

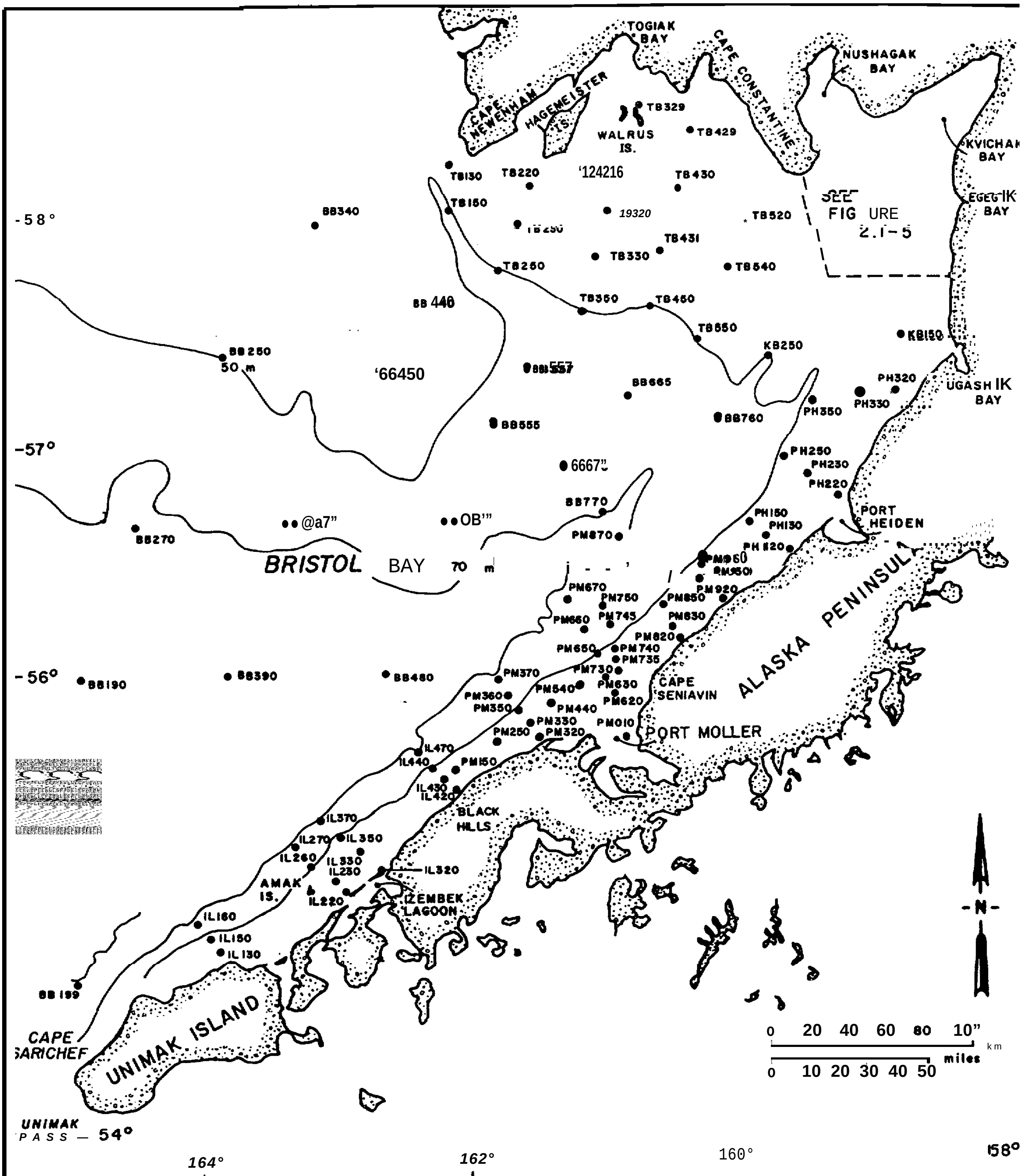
FIGURE 2.1-3

TABLE 2.1-1

SUMMARY OF FIELD SAMPLING EFFORT

Type of Sampling	Cruise 83-1 69(72)(a)	83-2 16(17)	83-3 88(64)	83-5 47(48)
CTD casts	76		76	47
Van Veen bottom grabs	2			
Shipek bottom grabs	46		20	12
Rock dredges	51		42	16
Trynet otter trawls	50		78	35
Bongo net tows	77	16	79	24
Tucker trawls	16		6	
Sameoto neuston sampler tows	4			
Shrimp pot sets	3		12	
Crab pot sets			5	
Fathometer surveys (hrs/nm)	12.3/-(b)		16.0/97	22.0/68
Side-scan sonar surveys (hrs/nm)				19.6/52

(a) Survey stations occupied (planned).
(b) Not recorded

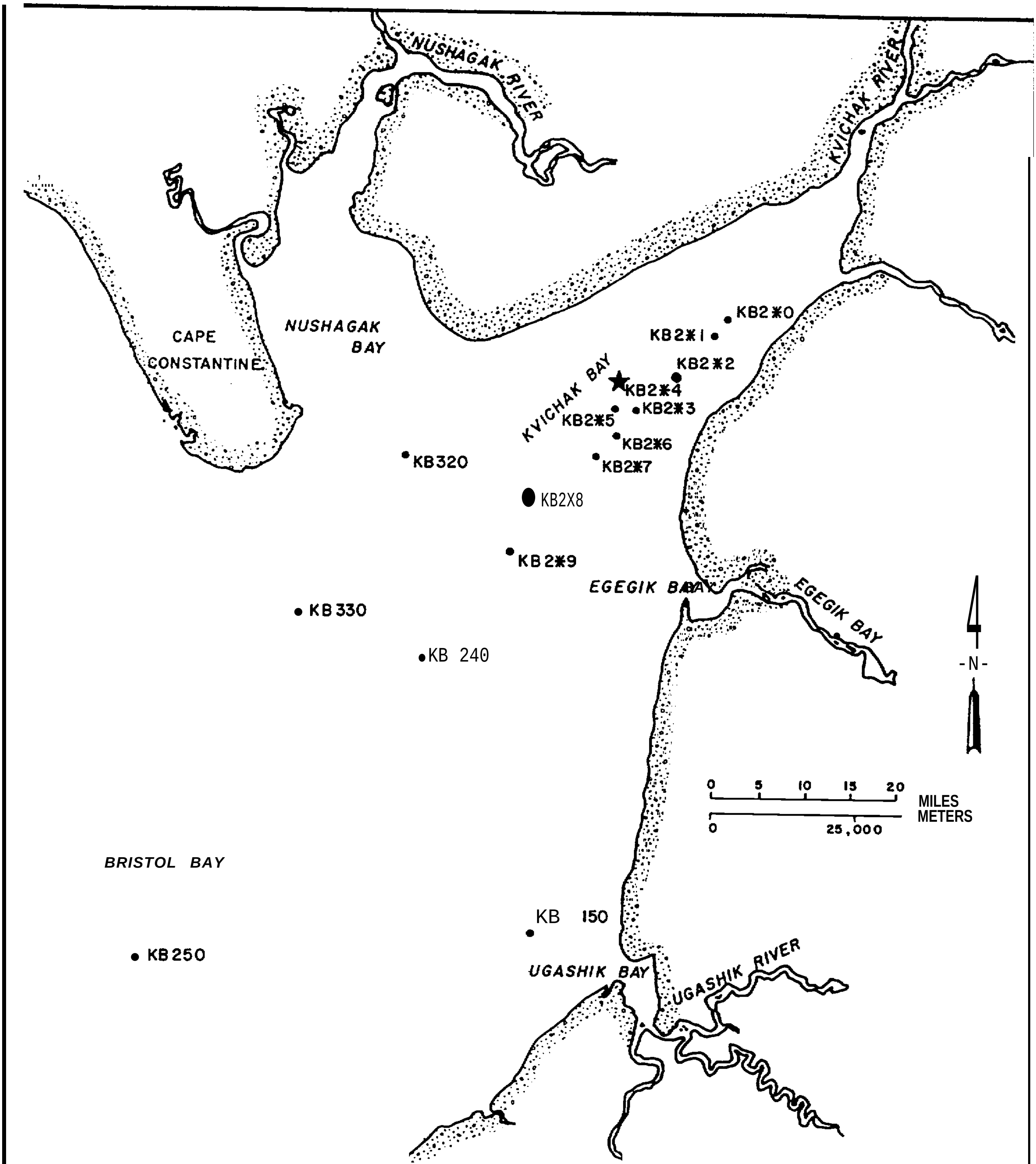


BB - BRISTOL BAY
IL - **IZEMBEK** LAGOON
PM - PORT MOLLE R
PH - PORT HEIDEN
KB - KVICHAK BAY
TB - **TOGIAK** BAY
(See text for explanation of numbers.)

BRISTOL BAY
RED KING CRAB

STATION IDENTIFICATION NUMBERS

FEBRUARY 1984 | **FIGURE** 2.1-4



• = SAMPLING STATION

★ = INTENSIVE SIDE SCAN SONAR SURVEY SITE

BRISTOL BAY
RED KING CRAB

STATION IDENTIFICATION NUMBERS
IN THE KVICHAK BAY VICINITY

301

FEBRUARY 1084

FIGURE 2.1-6

2.1.2 Field Gear and Sampling Methods

Physical Environment. Temperature and conductivity data were collected with the *Miller Freeman*'s CTD system. Depth-specific conductivity and temperature were later converted to salinity using a NOAA computer algorithm. Near-surface and near-bottom salinity data were selected for correlation with the observed larval and juvenile red king crab distributions. Near-surface, instead of surface, salinity (and temperature) values were selected for two reasons: 1) the shallowest CTD readings varied between 0.2 and 1.5 m; and 2) a subsurface value was thought to be more representative for correlation to organisms collected in oblique plankton tows. The near-bottom values were generally recorded about 5 m off the bottom.

Sediment samples were collected primarily with a Shipek grab during cruises 83-1 and 83-3; a few sediment samples were taken with a Van Veen grab during cruise 83-1. A sample of surface sediment was scooped from the grab sample, placed in a labeled plastic bag and frozen for later analysis. A field description of each sediment sample was recorded in the chief scientists' field notes during cruise 83-1.

During cruise 83-5 (September), a side scan sonar unit was used in an attempt to discern gravel substrates from silt and sand. A 500 kH_z Klein Associates, Inc. fish was towed at approximately 15 m from the bottom. Scope (wire out) and towing speed were varied to achieve distance above bottom, but in general the target speed relative to the substrate was 2 knots. A path width of 150 m was selected. Results were printed with a Klein Associates 521 T continuous recorder. Trynet trawls and Shipek grabs were then collected to ground proof the side scan traces. Two station locations were selected for intensive side scan sonar surveys: PM730 (Figure 2.1-3) and KB2*4 (Figures 2.1-3 and 2.1-5).

Larvae. Larval red king crab distribution and relative abundance were documented with standard net hauls over transects designed to fi 11 existing data gaps and to establish a continuing program. The primary sampling method for collecting larval red king crabs was the standard oblique bongo net tow in order to facilitate comparisons with previous Alaskan plankton and larval decapod collections both in Bristol Bay and off Kodiak Island. The nets were fished in CALCOFI fashion (Smith and Richardson 1977) to a depth of 80 m, or 10 m above the bottom, whichever was less. Eighty meters was selected as the bottom depth to be fished because crab megalopae are known to vertically migrate down to a depth of at least 70 m, but apparently not to 90 m (Ito and Ikehara 1971; Kendal 1, et al . 1980). The objective of the bongo net collections was to sample all of the larval crabs in the water column independent of time of day when sampled.

The bongo nets used were paired 0.333 mm (333) and 0.505 mm (505) mesh nets 60 cm in diameter with a length:width ratio of 5:1. These mesh sizes have been used in previous Alaskan plankton and larval decapod collections (Armstrong, et al. 1981a; Haynes 1974; Kendall, et al. 1980). A TSK and/or a General Oceanics "bullet" flowmeter was attached at the mouth of one or both of the nets. Collections were preserved in the field with 4 percent formalin and BHT added to preserve color of the larvae.

Two additional sampling devices, a Tucker trawl and a neuston net, were also utilized at two stations to characterize diel vertical stratification, which may be important for potential oil impact assessment. The sampling design utilized followed that of Kendall, et al. (1980) to assure a good comparison. The mesh size of both nets was 0.505 mm and the depths sampled were O, 10, 20, 30, 40 and 50 m. Sampling was done at dawn, midday, dusk and midnight.

Epibenthos. All of the epibenthic sampling was conducted from either the NOAA Ship Miller Freeman and its MonArk launch. Sampling days consisted of 24 hours on all cruises with the use of two scientific crews. Each station was surveyed prior to bottom sampling with the ship's 50kH Simrad fathometer in order to assess the trawlability of the bottom and determine the selection of sampling gear.

Samples of epibenthic organisms were obtained with trynet trawls and rock dredges; these gear are described in Table 2.1-2. The trynet was generally the preferred gear for apparent smooth, flat bottoms, whereas the rock dredge was used where the bottom appeared to be rocky or broken. A number of trynets were damaged or lost when sampling was attempted on rough bottoms. Several stations were sampled with both gear types in an attempt to compare their performance. The scope (towing wire to water depth ratio) and the towing speed were adjusted by the Miller Freeman fishing crew to maximize gear efficiency. The trynet was towed with scopes ranging from 3.0:1 to 4.5:1 and ship speeds of 2.5 to 3.5 knots. The rock dredge was towed with a scope of 4:1, and ship speeds in the range of 1.0 to 3.0 knots.

Quantitative try net and rock dredge samples were placed on a sorting table, characterized in field notes, and sorted to the lowest possible taxonomic groups. Voucher specimens of many taxa were preserved for further identification or verification. Samples were carefully searched for small red king crabs. Taxonomic groups were weighed on a large fisheries deck scale (for large organisms or large samples) or a triple-beam dial-type gram scale (for small organisms or samples). All organisms were counted, with the exception of colonial forms or small attached fauna. Very large samples were subsampled, and the total sample weights and counts were extrapolated from the subsample data.

All red king crabs and Tanner crabs were measured for length (king crabs) or width (Tanner crabs), and information on sex, maturity, shell condition, egg condition and external parasites was recorded. Individual weights were obtained for all king crabs except the very small young-of-the-year, which were frozen for later analysis. Lengths

TABLE 2.1-2

EPIBENTHIC SAMPLING GEAR

Gear Type	Gear Description
Trynet trawl	Headrope length: 5.38 m
	Doors: Cruises 83-1 and 83-3; wood, approximately 0.4 x 0.9 m with extra heavy shoe Cruise 83-5 aluminum
	Bridles: 18.3 m, 3/16 in. (0.48 cm) stainless steel (Cruise 83-1, part) 3/8 in. (0.95 cm) nylon (Cruise 83-1, part) 1/2 in. (1.3 cm) steel cable (Cruise 83-1, part, Cruises 83-3 and 83-5)
Rock dredge	Mouth : 0.91 m x 0.41 m, steel frame
	Chafing gear: Large mesh nylon netting with poly-line whiskers

were recorded for subsamples of large catches of yellowfin sole, rock sole, Pacific cod, walleye pollock and several other fish species. Stomachs of these species were examined for content when time allowed.

A number of rock dredge samples were treated qualitatively, primarily in areas of high juvenile abundance. These samples were described in field notes (see Appendix C) and searched carefully for juvenile crabs. Crabs from these samples were measured and data recorded as described above.

Field coding forms were used to record all taxonomic identifications, counts, weights and size information. A separate coding form was used to record location, time, depth and other pertinent information for each sample; this information was taken directly from the Marine Operations Abstract (MOA) kept by the bridge Duty Officer. Observational data, such as sample descriptions and fish stomach contents, were recorded in the Chief Scientist's field notes (see Appendix D).

2.1.3 Limitations

The most serious limitation in sampling juvenile king crab is the lack of suitable fishing gear (Powell and Nickerson 1965). Any surface-deployed device designed to sample early juveniles can at best be considered only as a reconnaissance tool. The rough terrain where early juvenile king crab are found in the coastal waters of the North Aleutian Basin severely limits attempts at quantitative sampling. The epibenthic data collected during this study are therefore considered qualitative; any calculated density and biomass numbers should be viewed as estimates, their greatest value being for within-study comparisons. The data resulting from trynet samples are probably the most accurate due to the generally reliable fishing behavior of this gear, which was used primarily on smooth, small grained bottoms. The rock dredge, used on rough bottoms, has erratic fishing behavior, apparently similar to that of the bottom skimmer described by Sundberg and Clausen (1979).

2.2 Laboratory Methodology

2.2.1 Sediment Analysis

Homogenization was accomplished by kneading the sample bag for several minutes. Following digestion of organics, the samples were wet sieved on a No. 230 sieve. Material passing through the sieve was then transferred to a settling chamber; the remainder was dried at 103"C, cooled, weighed and placed on a nest of sieves of decreasing size (Nos. 5, 7, 10, 14, 18, 25, 35, 45, 60, 80, 120, 170 and 230). The material retained on each sieve was then weighed. Approximately 30 grams of the material which passed through the No. 230 sieve were transferred to a settling chamber; 5 ml of sodium hexametophosphate was added and diluted to 1 liter with deionized water. The samples were allowed to soak for 12 hours. A settling cylinder was then filled, thoroughly mixed, returned to vertical position and 25 ml aliquots withdrawn at specified times and depths. The aliquots were placed in a tared 50 ml beaker which was covered and dried in an oven at 90°C. The beakers were then reweighed after cooling for one hour.

2.2.2 Larval Counts

The preserved samples were first either subsampled using a Folsom plankton splitter or rough sorted for decapod larvae in their entirety. The decision of whether to sort the entire sample or to split it depended on its size and condition. The general, subjective rule governing this decision was that if the sample was "clean" and had a volume greater than 0.15 liter, it was subsampled. Samples were considered "clean" if the volume of gelatinous zooplankton was low and there were no large phytoplankton aggregations, both of which would interfere with splitting.

Nest samples were counted in their entirety; however, as needed, samples were sequentially divided with the plankton splitter until 100 to

200 individuals of the most common single larval growth stage of red king crab were left to be enumerated in a single split. Repeated splitting until each common organism has numbers between 100 and 200 in a given subaliquot is a common zooplankton counting method (Jacobs and Grant 1978). The level of confidence for the total number of larval red king crab in every sample usually was in excess of 0.90. This conclusion was obtained through the following reasoning. Since the organisms have been randomly distributed by the plankton splitter (Jacobs and Grant 1978) the counts of each subsample should obey the Poisson distribution (Elliott 1971). Under these conditions the sample variance equals the sample mean (Snedecor and Cochran 1967) and the optimal number to be counted equals the reciprocal of the square of the desired confidence level (Cassie 1971; Watt 1968). For the 0.90 level of confidence, the number is 100 organisms, while 400 organisms will produce a 0.95 level of confidence.

All counted samples and splits were saved separately for any necessary future verification. Counts were recorded on a coding sheet.

2.3 Data Reduction

The raw larval counts were converted into population density data. For the rarer stages the conversion is merely division of the total number counted by the volume (m^3) of the sample. Where aliquots were taken, the density values obtained were multiplied by the reciprocal of the size of the split used. Areal density (per 100 m^2) was obtained by first dividing the volume sampled by the sampling depth, then dividing 100 m2 by the resulting area and multiplying sample counts by this second value. The second calculated value is necessary to convert the counts from a sample-specific area into standard counts per 100 m^2 (see discussion in Armstrong, et al . 1983 b).

The final stage of data reduction was conversion of VTN formats into OCSEAP formats, File Type 124-Zooplankton and 123-Fish and Shellfish

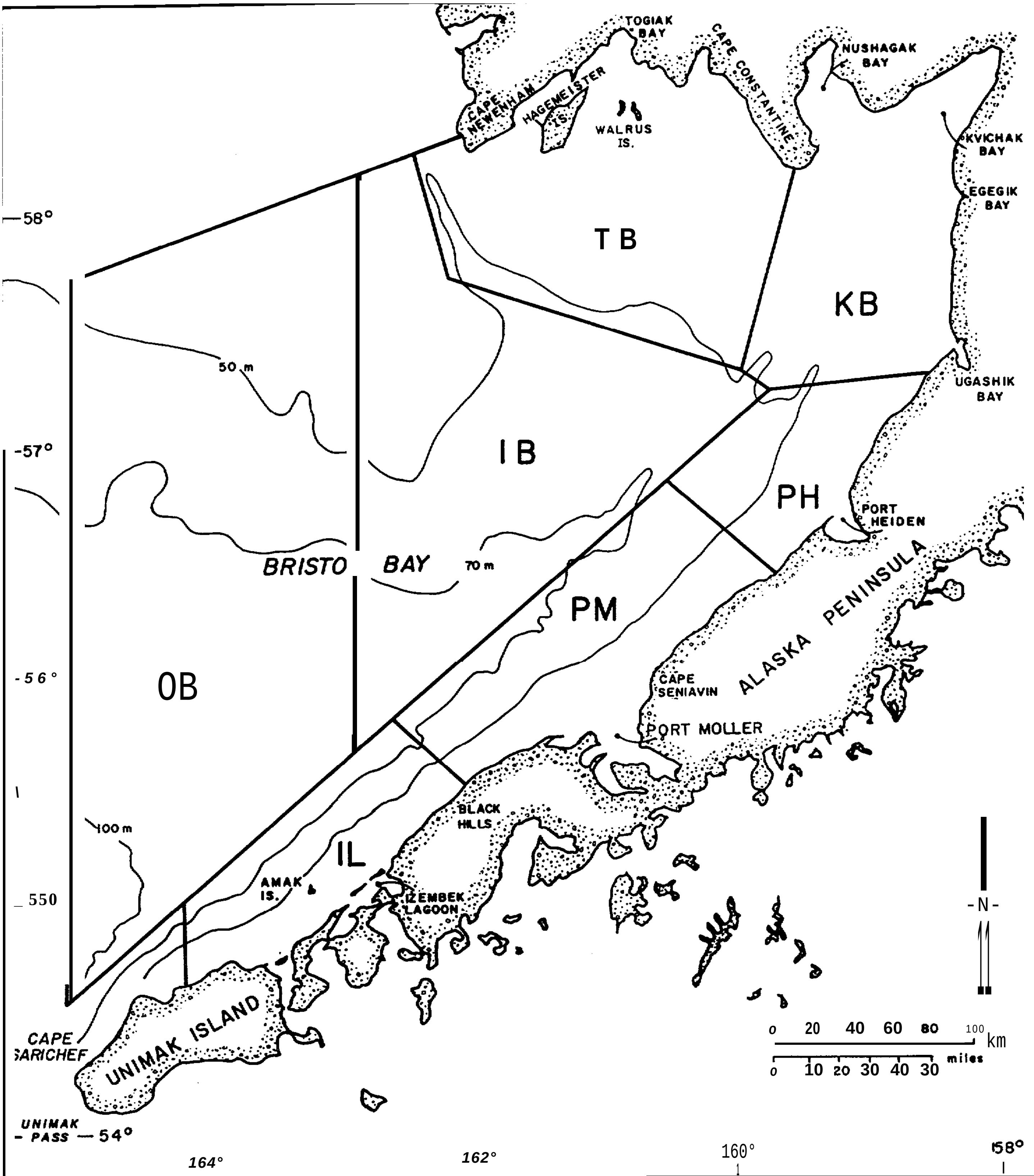
Resource Assessment. The conversion utilized computer programs previously developed for this purpose during OCSEAP RU608 - Kodiak Shelf Holozooplankton Distribution and OCSEAP RU623 - North Aleutian Shelf Sea Otter contracts. The converted data were put onto a magnetic tape at Mellonics Information Center, Canoga Park, California, and the final data product tape was then submitted to the OCSEAP Project Data Manager.

2.4 Data Analysis

Larval Crab. The crab larvae were initially described with a set of summary tables and density maps by stage and cruise. Seven subareas (strata) were selected for statistical comparison of areal results. These areas were shown in Figure 2.4-1, and are a modification of sampling strata defined by Armstrong, et al. (1983b) for analyses of data collected 1976-1982.

The second statistical treatment was a multiple correlation analysis, producing a correlation matrix between all of the included variables, after which multiple linear regression was run on selected variables. Prior to statistical treatment, the data were tested for normality, and as they were not normally distributed, the data were log-transformed in order to obtain valid statistical results. For larvae, the initial list of variables included temperature and salinity at five and 10 meters depth, time of day, time of year, station position, bottom depth and maximum depth of tow. Multiple correlation analysis was selected as the initial statistical treatment because it is a mathematically succinct method of determining the relative magnitude of different interactions within a large set of variables. In addition to the statistical analysis of relative abundance and apparent distribution, a limited analysis was performed on the Tucker trawl and neuston net samples to test for the presence of larval diel vertical stratification.

Post-larval Crab. Biological information collected for post-larval red king crabs included carapace length, weight, sex, shell condition and



OB - OUTER BRISTOL BAY
IB - INNER BRISTOL BAY
PM - PORT MOLLER
PH - PORT HElDEN
KB - **KVICHAK** BAY
TB - **TOGIAK** BAY
IL - **IZEMBEK** LAGOON

BRISTOL BAY
RED KING CRAB

STUDY AREA SUBAREAS
FOR DATA ANALYSIS

FEBRUARY 1084 | FIGURE 2.4-1

egg condition" for females. Analysis of these data was performed without the use of the computerized data management system due to the small sample size. Length data were tabulated to show the distribution of crabs by age class. Geographical plots were produced to show the distribution of post-larval crabs by age within each cruise.

Assignment of relative age at size for the immature king crab was taken from Weber (1967) who examined the growth of immature king crabs from the southeastern Bering Sea. The average and range of the carapace length of crabs at ages 1, 2 and 3 are 11 and 9-14 mm, 35 and 29-41 iron, and 60 and 50-67 mm, respectively. Weber (1967) gave the average size of age 4 crab as 78 mm; however, no size range for this age was presented. After examination of the means and ranges of smaller age classes, a conservative range of ±4 mm (74-82 mm) was assumed for age 4 crabs. The size of 82 mm was chosen as the cut-off for age 4 crabs, in part because the smallest ovigerous female that was found in this survey was 83 mm. All crabs >83 mm were assigned the age of 4++. Since growth for the sexes is similar until the fourth year of life at approximately 80 mm (Weber 1967), size data for males and females to 82 mm were combined.

The emphasis of the post-larval part of this study is on crabs of age 3 years and younger. Accordingly, these individuals (<67 mm) are referenced in this report as "juvenile" crabs, while individuals older than 4 years (>83 mm) are "adults". Crabs age 3+ and 4 (>68 and <83 mm) are included in the sections dealing with adults.

The distribution data were tabulated by station for each cruise. Because certain stations were sampled more than others, these data were standardized by calculating a catch per station value for each of the six sampling subareas (for this purpose, subareas IB and OB were combined as BB). The overall mean catch per station for each cruise was calculated as the sum of the mean catches per station in a subarea divided by the total number of stations sampled in that subarea.

Epibenthic density and biomass data were analyzed in two ways. First, mean biomass values were calculated for each major taxonomic group per crui se; these values were labeled mean catch per unit effort (CPUE) in units of gin-2. These data are presented in tabular form to show the relative importance of major fish and invertebrate groups in the samples. The second major analysis of epifaunal data was cluster analysis. Cluster analysis using EAP (1982) involved a square root transformation of all data and appropriate standardizations. Dis-similarities or distances among the entities (samples or species) were calculated using the Bray-Curtis Index (Bray and Curtis 1957). Formation of the two dendrograms and the two-way matrix of sample and species groups involved flexible sorting with the addition of a step across distances re-estimation for the species groupings and the two-way matrix.

Post-larval king crab densities and related physical and biological environmental variables were examined using correlation and multiple linear regression analyses. For the purpose of these analyses, king crabs were divided into four age groups: 1) young-of-the-year or 0+; 2) ages 1, 1+ and 2; 3) ages 2+ and 3; and 4) ages 3+ and older (3++). The four physical variables were: 1) depth; 2) bottom water temperature; 3) bottom water salinity; and 4) percent gravel in sediment samples. The biological variables used were the mean sample biomass values for nine taxa: 1) flatfishes; 2) roundfishes (all fish except Pleuronectidae); 3) polychaete worms; 4) shrimps (including pandal ids and crangonids); 5) the sea star (<u>Asterias amurensis</u>); 6) the sea urchin (<u>Strongylocentrotus droebachiensis</u>); 7) sponge; 8) bryozoans; and 9) the sea onion (<u>Boltenia ovifera</u>). Biomass data were available for all of these taxa with the exception of bryozoan biomass from all quantitative trynet and rock dredge samples. Bryozoan biomass data were not always available due to the difficulty of separating this taxon from its substrate; however, the taxon was included in the analysis because of its apparent use as food by juvenile red king crabs (see Appendix F) .

SECTION 3.0

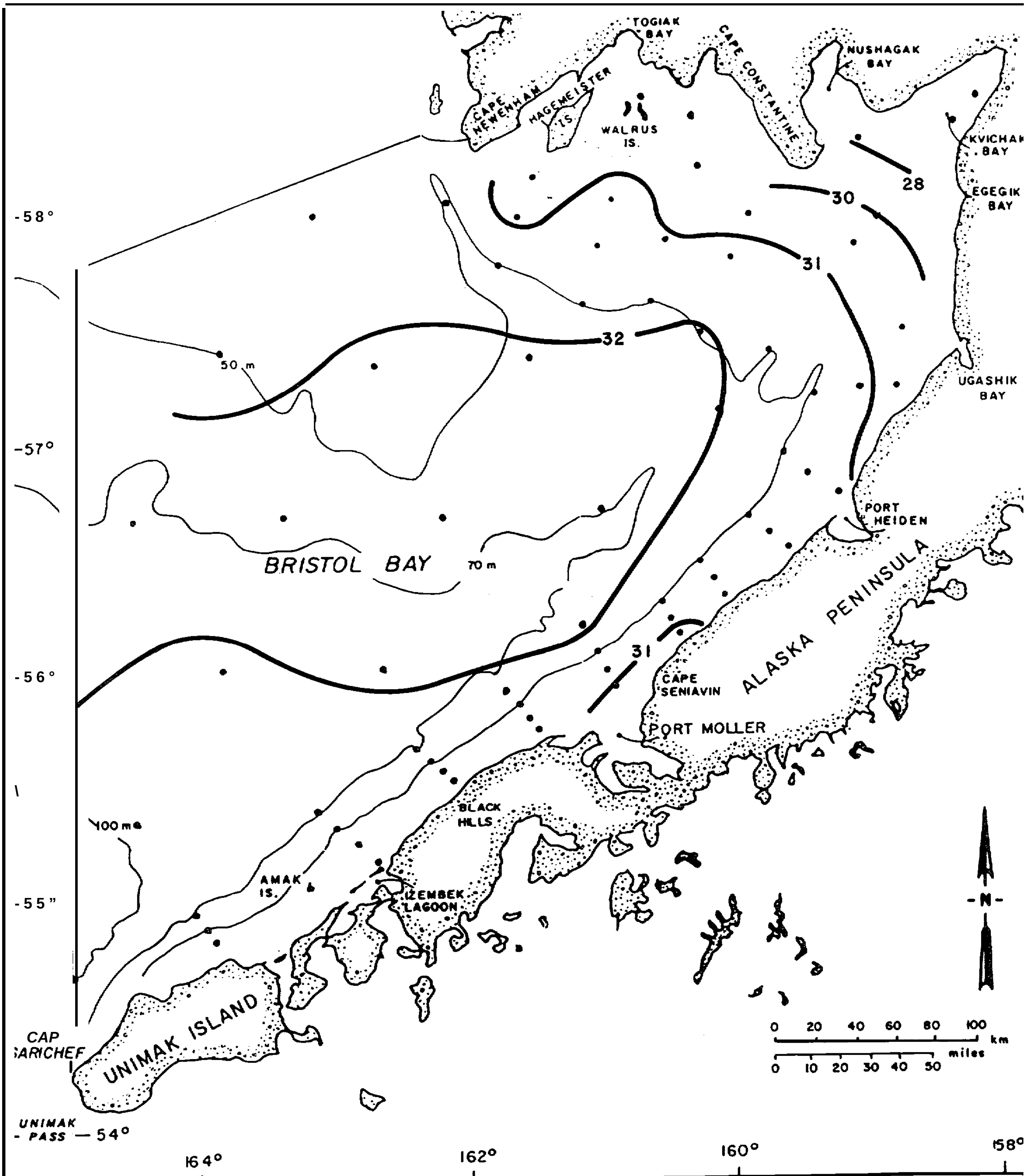
RESULTS

3.1 Physical Environment

3.1.1 Hydrography

Salinity. Near-surface salinity contours for the April, June and September cruises are presented in Figures 3.1-1, 3.1-2 and 3.1-3, respectively; near-bottom salinity contours are shown in Figures 3.1-4, 3.1-5 and 3.1-6. Salinity generally increased offshore. Maximum salinities at all depths were found in the deepest offshore parts of the study area and lower salinities were found onshore, especially near areas of freshwater runoff which included Kvichak and Nushagak Bays, Port Heiden and Port Moller. Very little vertical salinity stratification was observed during the study. Salinity decreased slightly over the study period and the lowest salinities were recorded during September in Kvichak Bay. The freshwater from Kvichak and Nushagak Bays apparently flows largely to the west, along the north side of Bristol Bay.

Temperature. Near-surface temperature contours for the April, June and September cruises are presented in Figures 3.1-7, 3.1-8 and 3.1-9, respectively; near-bottom temperature contours are shown in Figures 3.1-10, 3.1-11 and 3.1-12. Observed temperatures ranged from below 1° in April to over 12°C in September. The lowest temperatures were found at depth during the spring and the highest were associated with onshore areas in summer and fall. The strongest feature shown by the temperature data is the seasonal thermocline, which was most prominent during the June cruise (83-3). The maximum temperature differences between surface and bottom (>4°C) and the coldest bottom water during June, were observed offshore of the Black Hills vicinity (Figure 3.1-11). There was



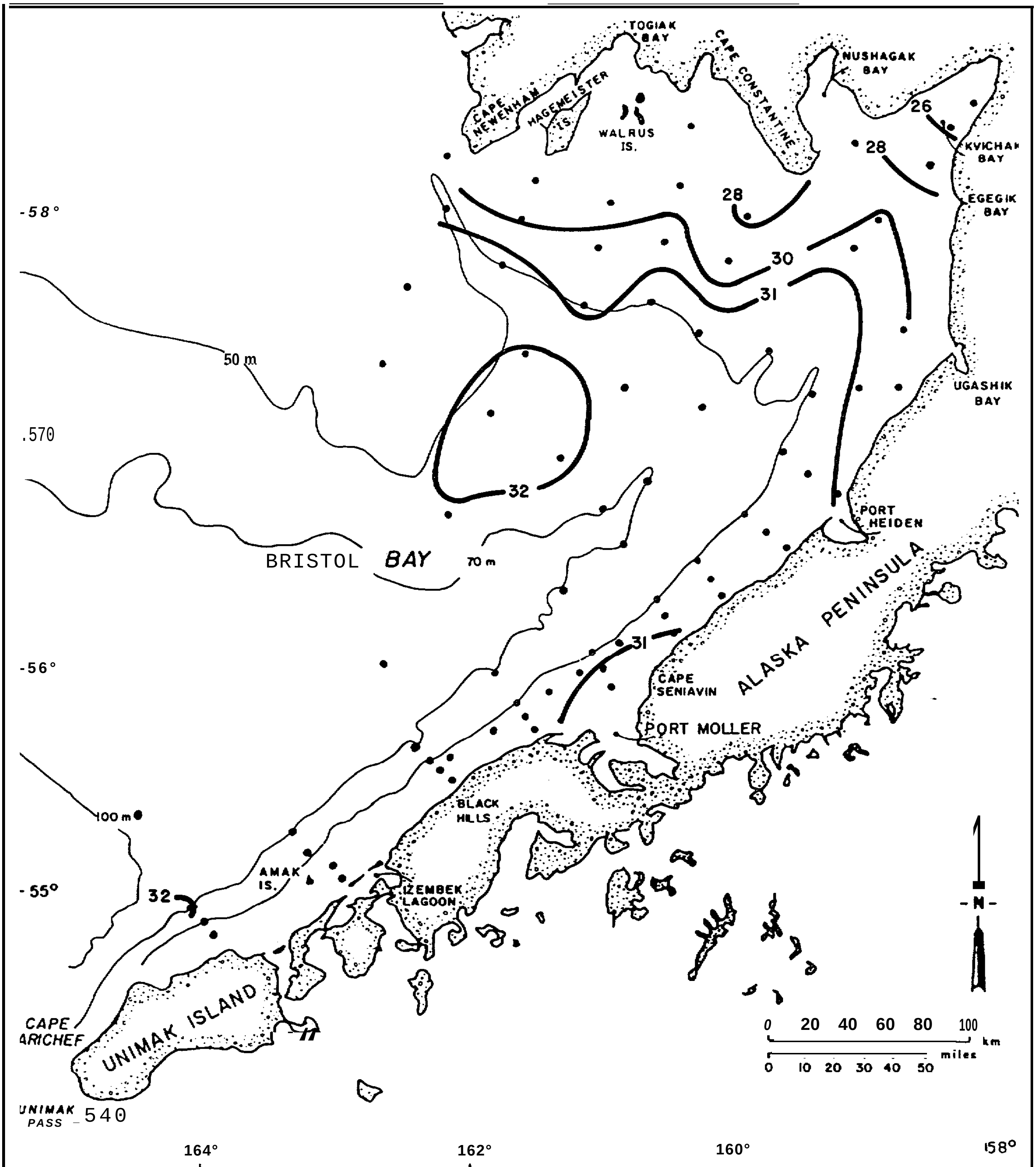
• : SAMPLING STATION

-3(3- = ISOHALINE(‰)

BRISTOL BAY
RED KING CRAB

CRUISE 83-1
10 METER SALINITY CONTOURS

FEBRUARY 1984 FIGURE 3.1-1



• = SAMPLING STATION

-30-= **ISOHALINE** (°/oo)

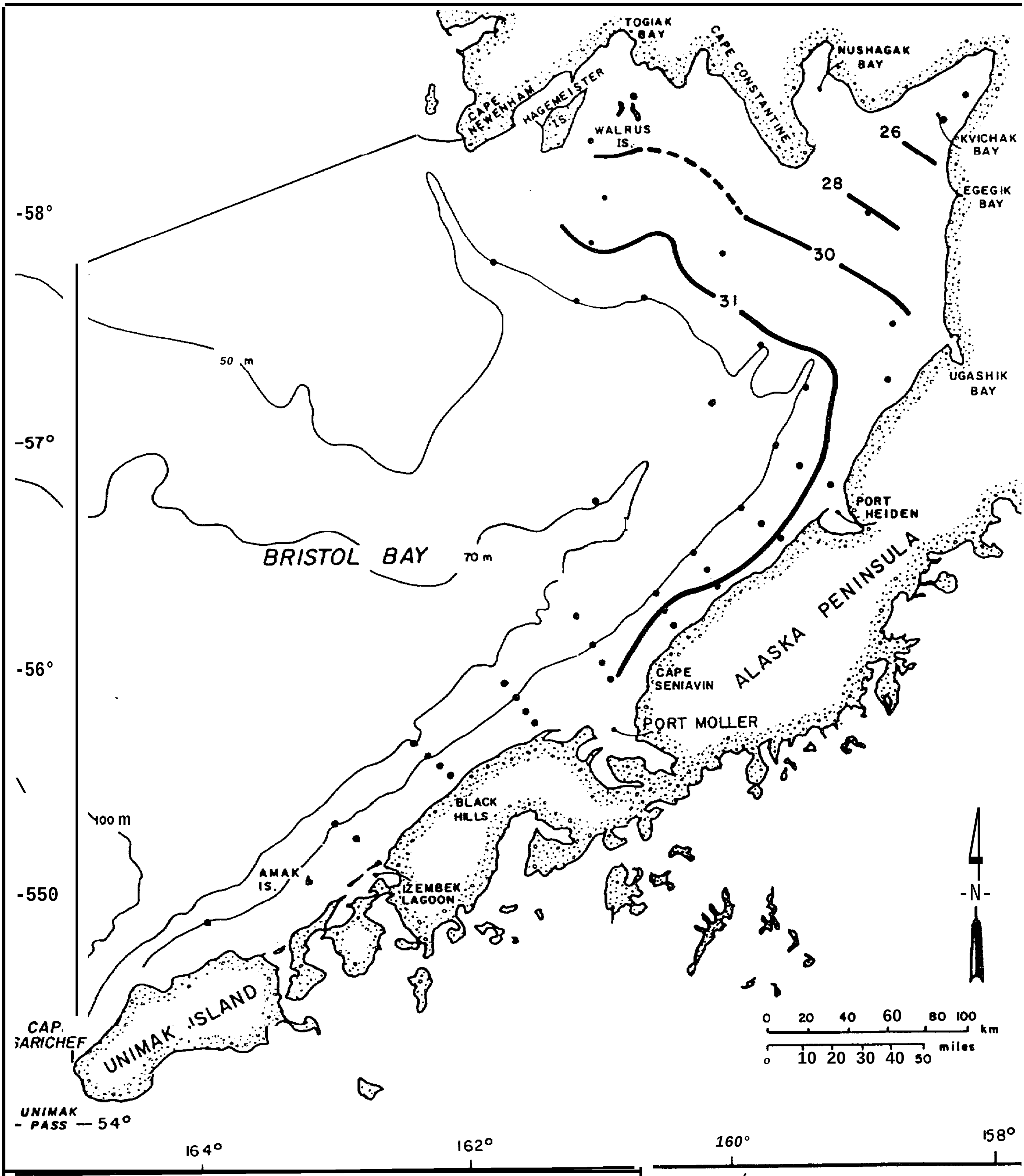
BRISTOL BAY
RED KING CRAB

CRUISE 83-3

10 METER SALINITY CONTOURS

FEBRUARY 1984 | FIGURE 3.1-2

 vtn



● = SAMPLING STATION

-30- = ISOHALINE (‰)

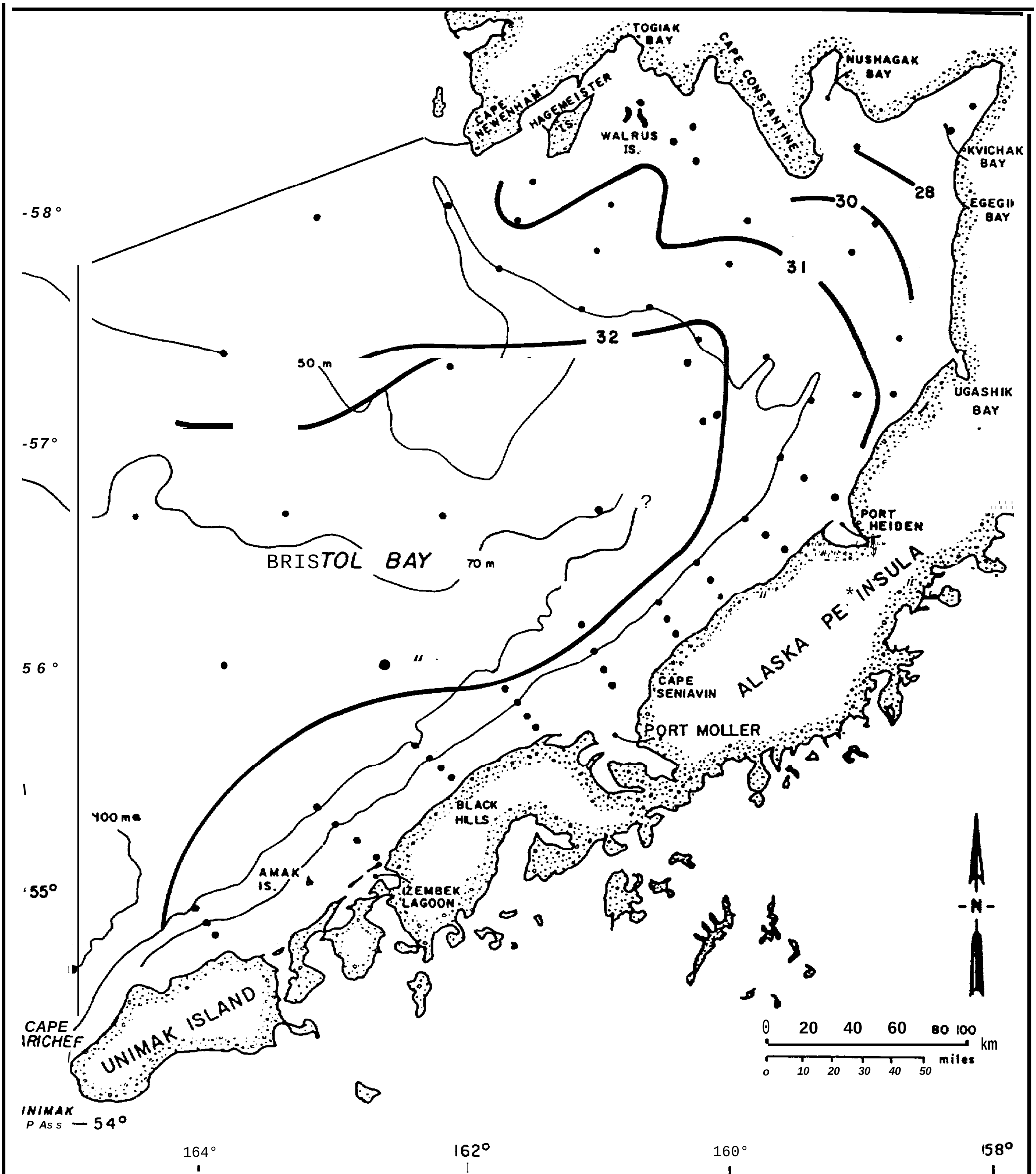
BRISTOL BAY
RED KING CRAB

CRUISE 83-5

10 METER SALINITY CONTOURS

316

FEBRUARY 1084 FIGURE 3.1-3



• = SAMPLING STATION

— 30 — = ISOHALINE (‰)

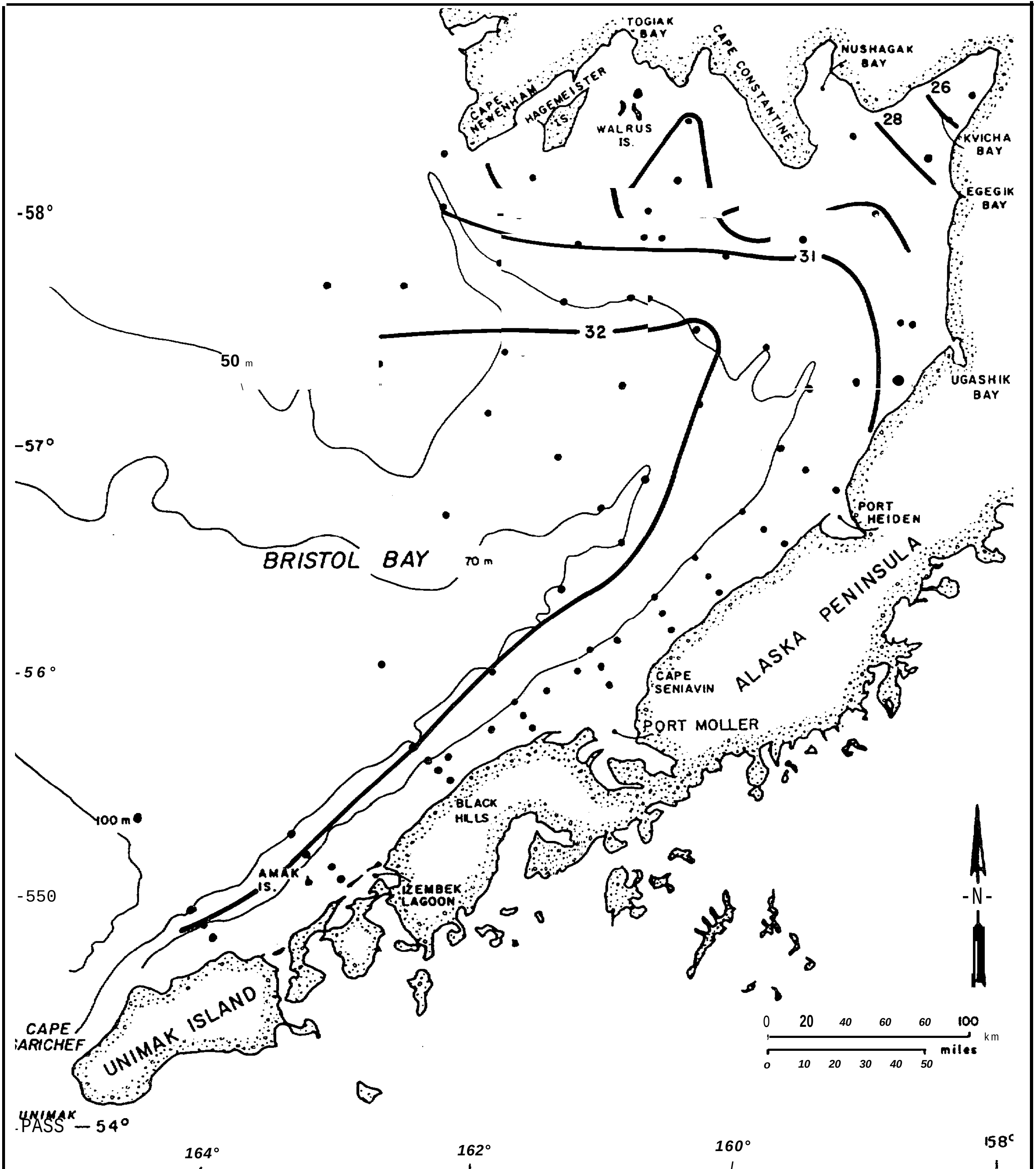
BRISTOL BAY
RED KING CRAB

CRUISE 03-1

BOTTOM SALINITY CONTOURS

FEBRUARY 1984

FIGURE 3.1-4



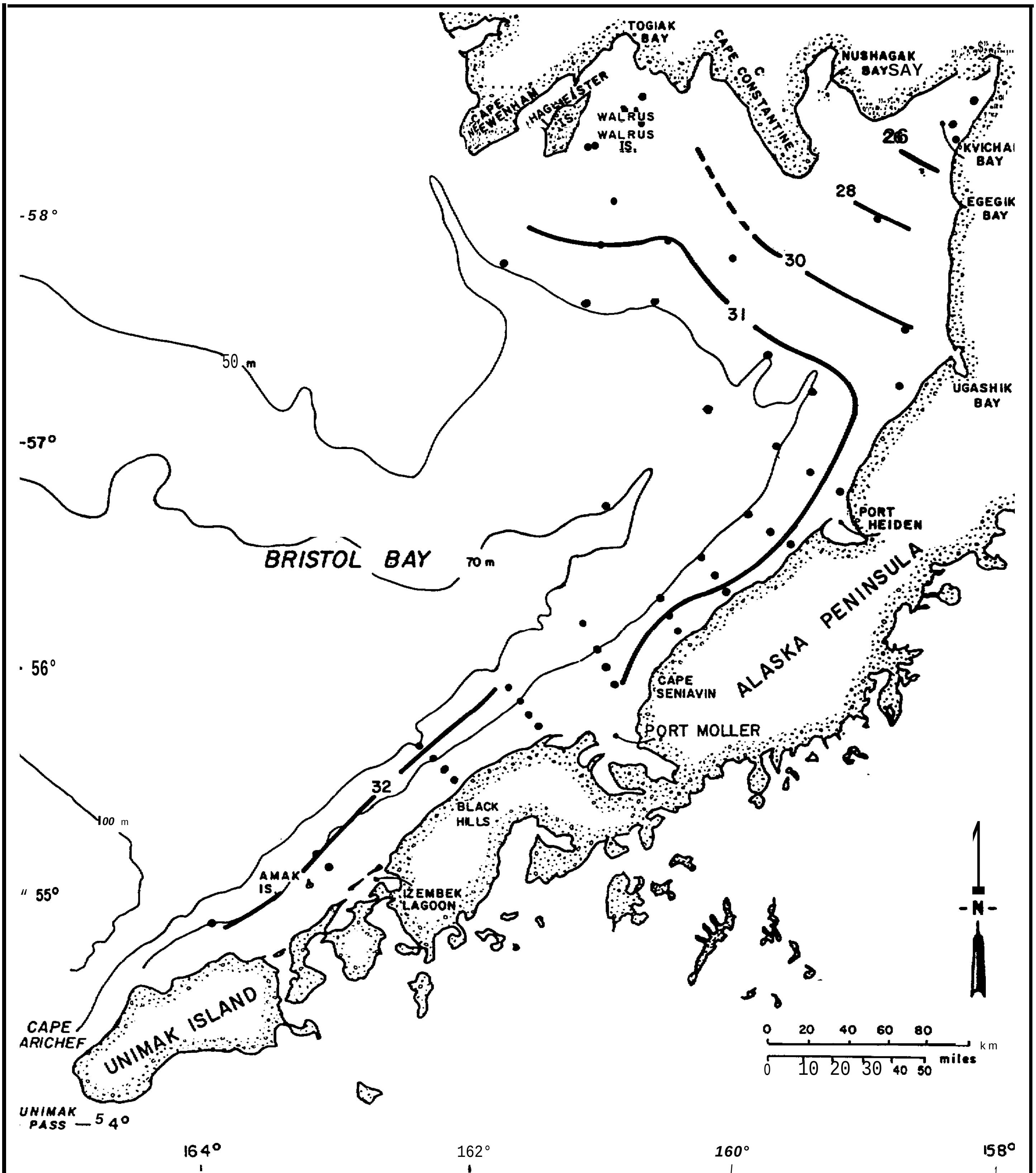
• =SAMPLING STATION

-30- = ISOHALINE (°/oo)

BRISTOL BAY
RED KING CRAB

CRUISE 83-3
BOTTOM SALINITY CONTOURS

FEBRUARY 1984 | FIGURE 3.1-5



• = SAMPLING STATION

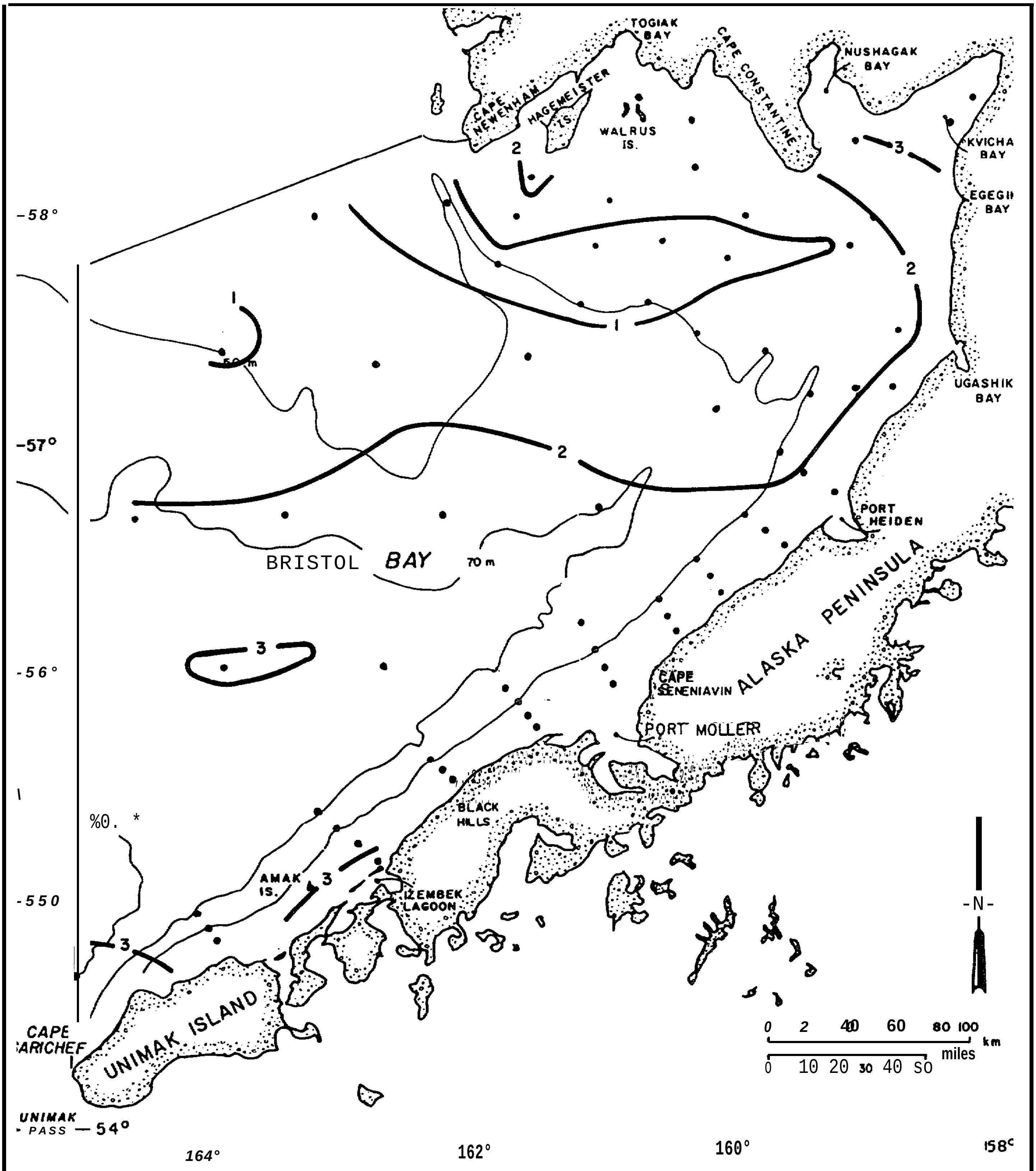
-30-= ISOHALINE (‰)

BRISTOL BAY
RED KING CRAB

CRUISE 83-5
BOTTOM SALINITY CONTOURS

FEBRUARY 1084

FIGURE 3.1-6



• = SAMPLING STATION

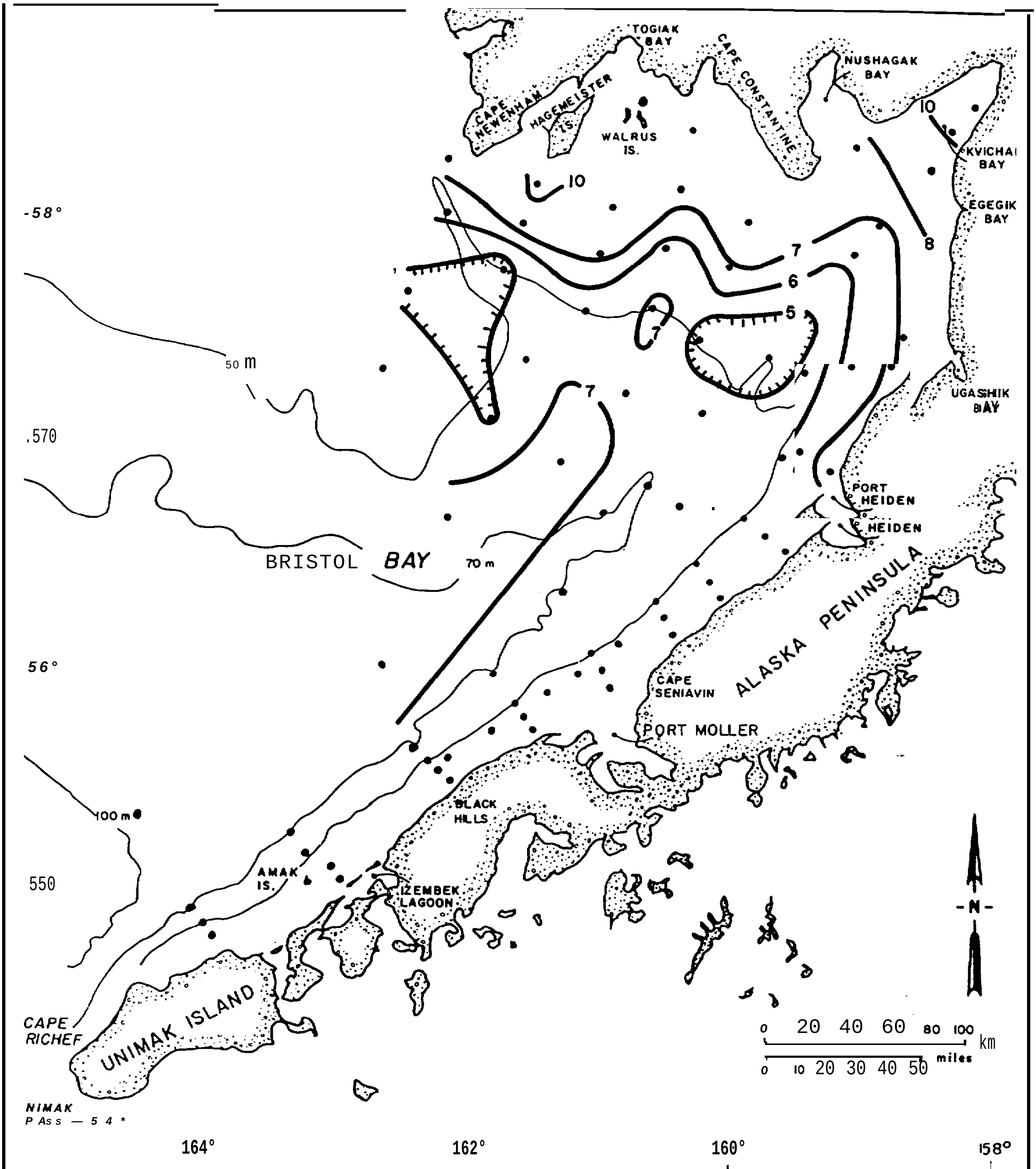
— 5 - = ISOTHERM (°C)

BRISTOL BAY
RED KING CRAB

CRUISE **83-1**

10 METER TEMPERATURE CONTOURS

FEBRUARY 1984 FIGURE 3.1-7



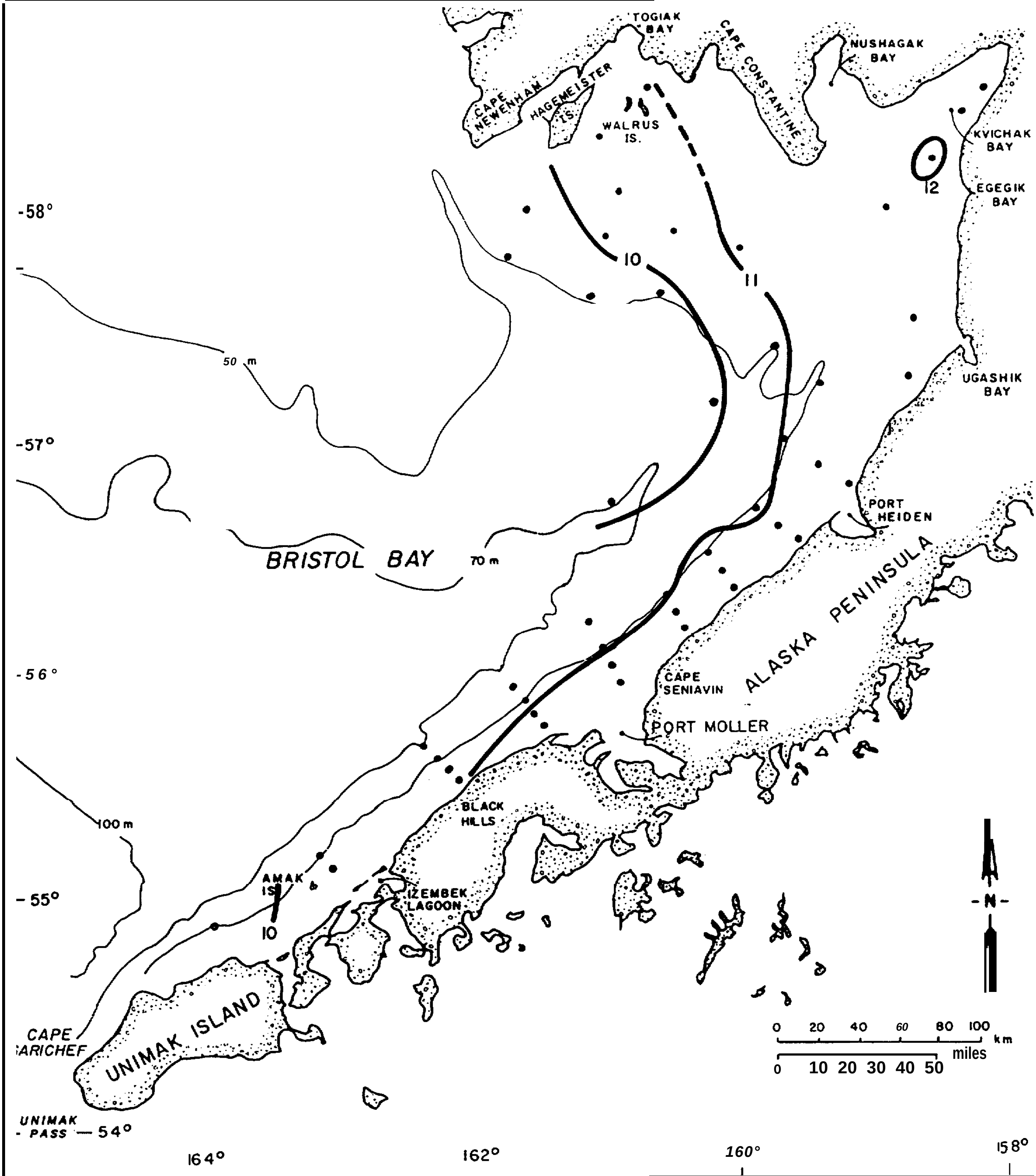
• = SAMPLING STATION

— 5 — = ISOTHERM (°C)

BRISTOL BAY
RED KING CRAB

CRUISE 83-3
10 METER TEMPERATURE CONTOURS

FEBRUARY 1984 FIGURE 3.1-8



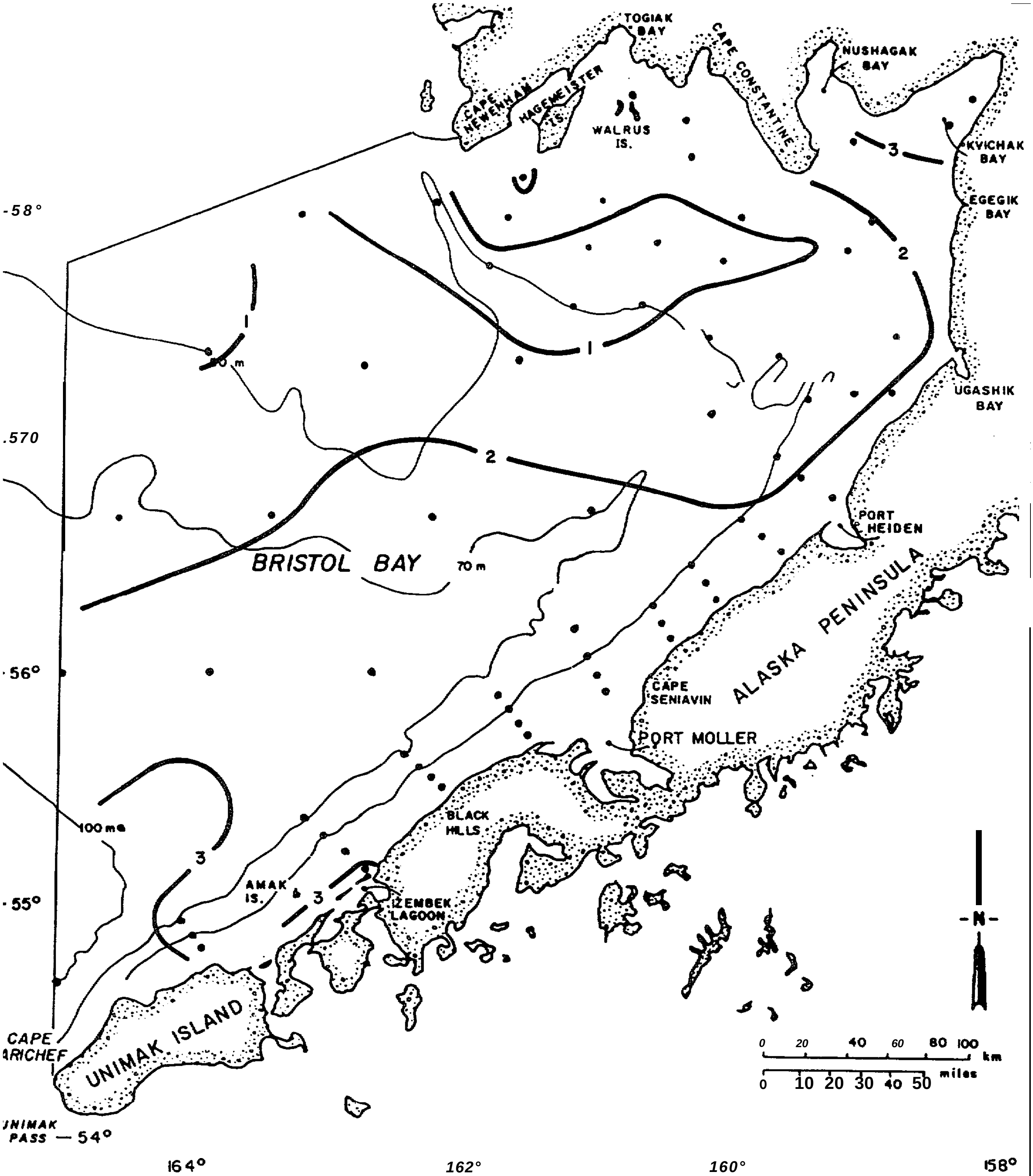
• = SAMPLING STATION

-5- = {SOTHERM ("C)

BRISTOL BAY
RED KING CRAB

CRUISE 83-5
10 METER TEMPERATURE CONTOURS

FEBRUARY 1984 | FIGURE 3.1-9



• = SAMPLING STATION

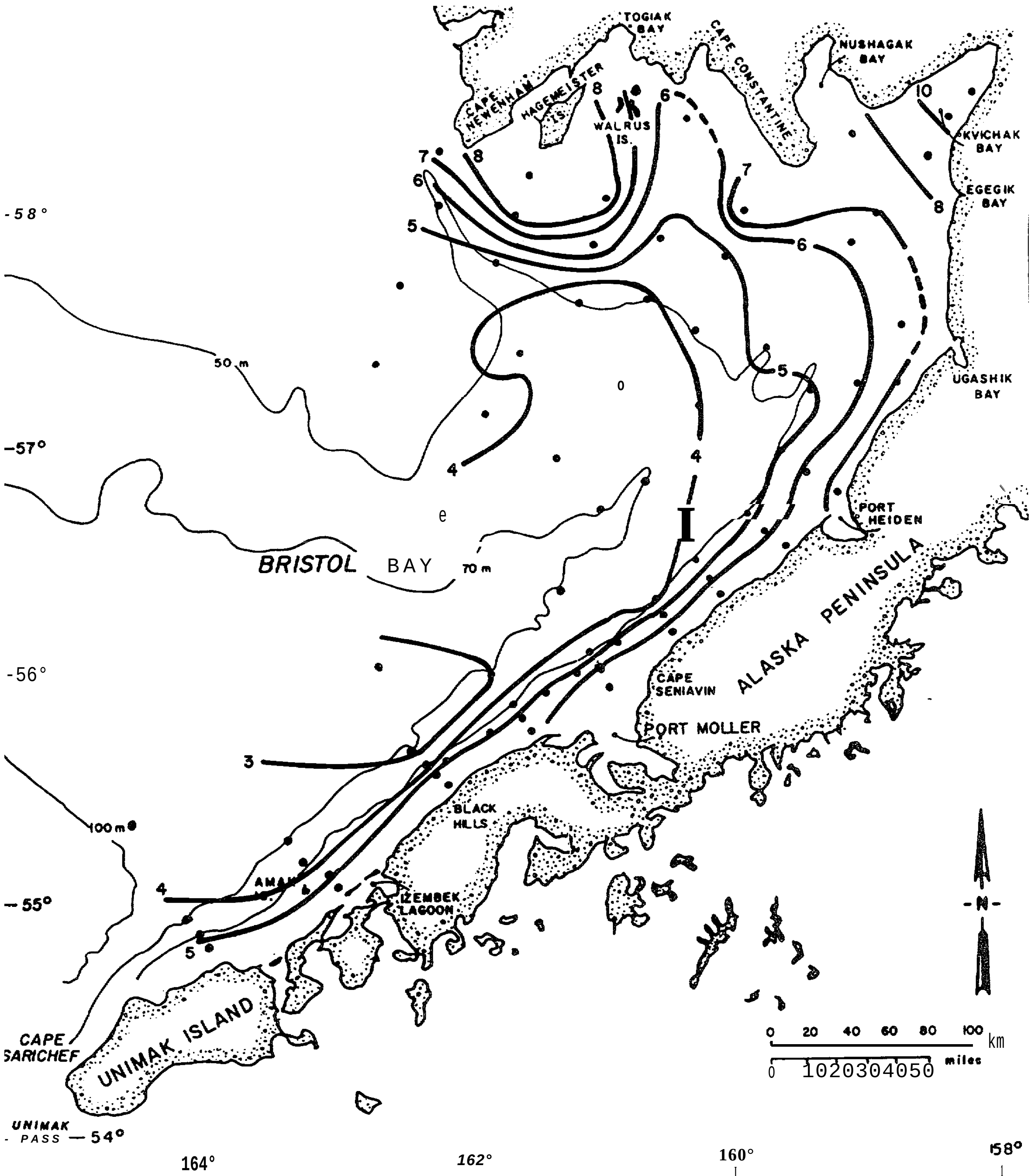
— 5 — = ISOTHERM (°C)

BRISTOL BAY
RED KING CRAB

CRUISE 83-1
BOTTOM TEMPERATURE CONTOURS

FEBRUARY 1984 | FIGURE 3.1-10

vtn



• = SAMPLING STATION

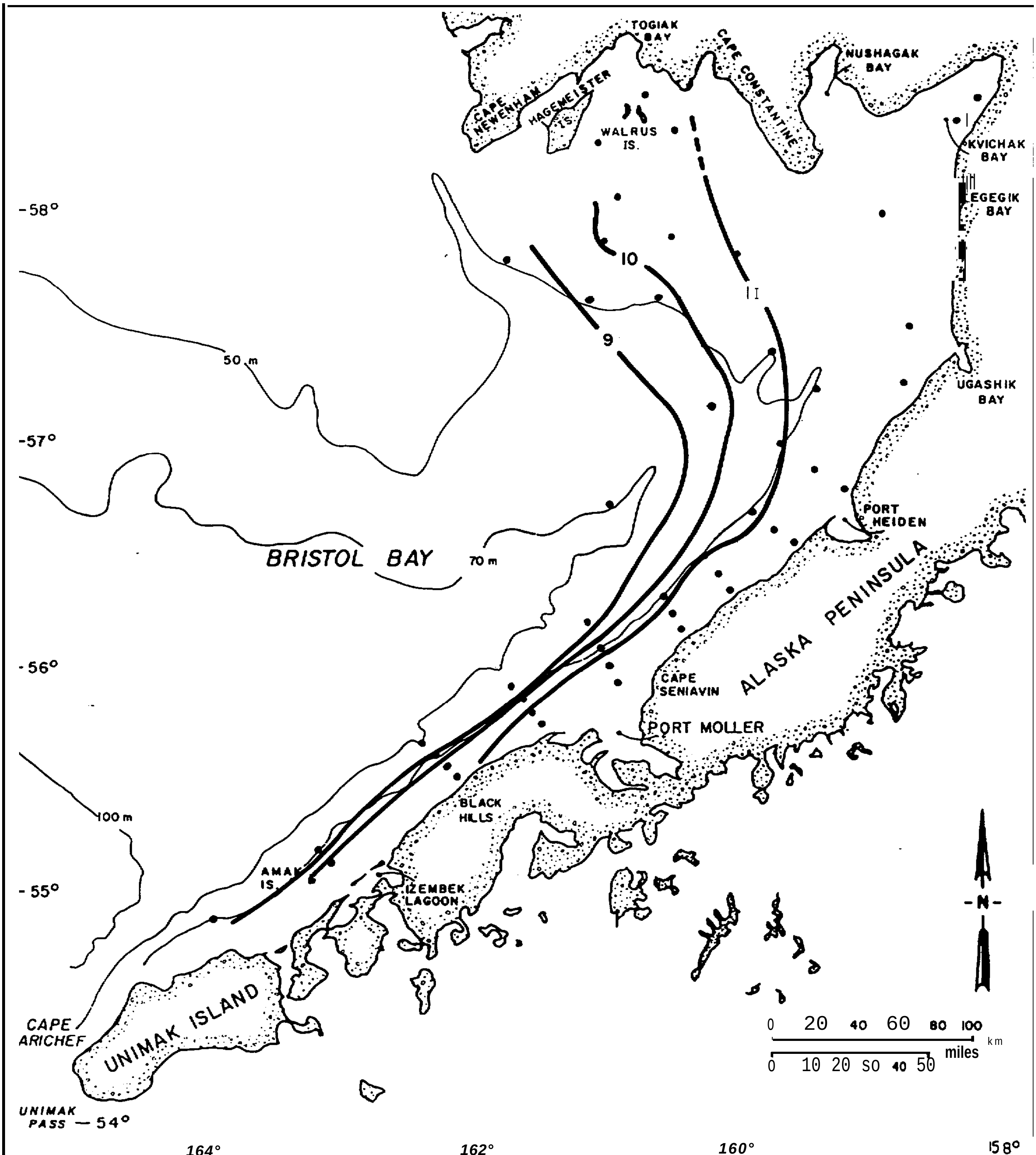
—5— = ISOTHERM (°C)

BRISTOL BAY
RED KING CRAB

CRUISE 83-3
BOTTOM TEMPERATURE CONTOURS

FEBRUARY 1984

FIGURE 3.1-11



• = SAMPLING STATION

—5— = ISOTHERM (°C)

BRISTOL BAY
RED KING CRAB

CRUISE S3-S
BOTTOM TEMPERATURE CONTOURS

FEBRUARY 1984

FIGURE 3.1-12

little vertical temperature stratification inshore of the 50 m isobath. The high temperatures on the northern side of Bristol Bay during June and September were apparently related to warm fresh water moving generally west from Kvichak and Togiak Bays.

3.1.2 Substrate Characteristics

Sediment Analysis. The results of the sediment analyses are presented in Table 3.1-1, which reports the percent sand, gravel and silt, geometric mean diameter and sorting index for the 60 samples analyzed. Most samples in the study area were predominated by sand, as shown in Figure 3.1-13. At least one sample from each of the study areas except Bristol Bay contained >10 percent gravel. Six of the seven KB samples contained from 42 to 91 percent gravel, four of the fifteen TB samples contained 41 to 62 percent gravel, and two of the nine IL samples contained 30 to 54 percent gravel. By contrast, samples from the Bristol Bay subarea contained little or no gravel, but had the greatest amounts of silt, ranging from 0 to 33 percent. Station TB130, near Cape Newenham, had 16 percent silt; none of the remaining stations sampled had >5 percent silt. The geometric mean diameter for the BB samples was lowest and the sorting index was highest. Samples containing gravel were poorly sorted by comparison to the deeper, Bristol Bay samples. The percentage gravel information is presented as contours (by orders of magnitude) in Figure 3.1-14. This figure shows the apparent large-scale distribution of gravel deposits in the study area.

Observational data concerning substrate material in trynet and rock/dredge samples are presented in Figure 3.1-15. The distribution of gravel or larger sized substrates from these observations agrees fairly well with the distribution obtained from sediment sample data. The Shipek sampler used to obtain sediments works poorly in larger grained sediments, thus, shell and cobble substrates were not adequately sampled. Observations indicated that substrates with significant amounts of whole and broken shell debris were found at 50 m and deeper

TABLE 3.1-1

SEDIMENT SIZE CHARACTERISTICS

Station	Depth (m)	Grain Size Percent Gravel	Sand	Silt	Gm[a]	So[b]
IL150	50	1.42	98.58	0	DL[c]	DL
IL160	62	0	100.0	0	0.69	1.43
IL220	20	0	100.0	0	0.57	1.40
IL230	30	0	99.84	0.16	0.20	1.28
IL260	60	0.22	99.78	0	0.28	1.24
IL270	70	0	99.78	.22	0.21	1.36
IL420	17	53.55	46.45	0	5.34	2.08
IL430	33	30.25	69.75	0	3.60	1.48
IL470	67	.47	99.44	.09	0.45	1.52
PM320	20	24.39	75.61	0	1.61	2.24
PM330	30	8.72	91.18	0.09	2.25	1.22
PM350	50	2.97	97.03	0	0.83	1.88
PM350	50	6.83	93.02	0.15	1.66	1.65
PM650	50	0	99.88	0.12	0.22	1.22
PM670	70	0	100.0	0	0.23	1.26
PM730	30	0	99.76	0.24	0.20	1.20
PM820	24	23.88	75.89	0.23	1.67	2.39
PM850	49	2.27	97.61	0.13	0.70	2.10
PM920	17	0	97.03	2.97	0.24	1.25
PM930	27	0.45	99.43	0.11	0.63	1.92
PM950	50	0.56	99.35	0.09	0.39	1.48
BB190	1	0	67.30	32.70	0.12	2.22
BB250	0	0	99.22	0.78	0.17	1.22
BB270	71	0	72.74	27.26	0.11	1.70
BB299	100	0	78.78	21.22	0.11	1.60
BB340	36	0	99.71	0.29	0.23	1.15
BB390	87	0	83.51	16.49	0.13	1.59
BB480	80	0	100.0	0	0.19	1.25
BB560	64	0	99.86	0.14	0.20	1.23
BB770	0	0	99.72	0.28	"0.27	1.33
KB2*9	7	42.05	57.67	0.28	1.75	5.98
KB2*0	22	89.17	10.73	0.10	21.82	1.97
KB2*0	22	61.30	38.70	0	5.27	5.29
KB2*4	20	90.51	9.47	0.02	20.97	1.74
KB2*4	22	71.58	28.33	0.09	8.94	3.02
KB240	5	0.13	99.80	0.07	0.43	1.47
KB320	2	46.54	53.35	0.11	1.88	5.84

TABLE 3.1-1

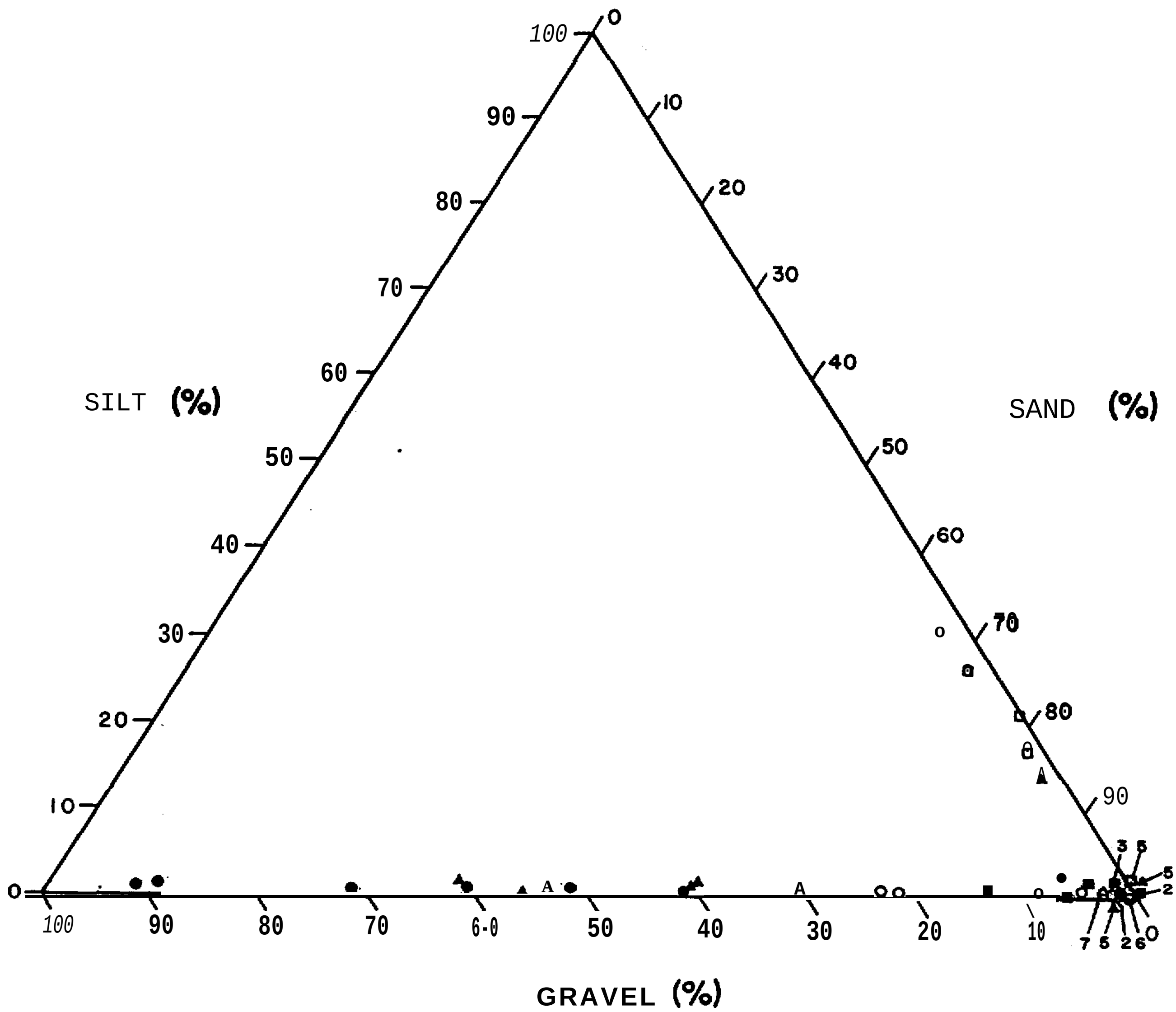
(continued)

Station	Depth	Grain Size Percent Gravel	Sand	Silt	Gm[a]	So[b]
PH130	28	4.31	95.69	0	1.15	1.79
PH150	50	0	99.65	0.35	0.31	1.30
PH220	20	5.32	92.31	2.38	0.28	1.28
PH230	29	5.49	94.42	0.09	0.42	1.46
PH250	55	0	99.56	0.44	0.31	1.43
PH320	17	0.27	99.46	0.27	0.32	1.23
PH320	20	2.20	92.69	5.11	0.60	2.37
PH330	29	14.30	85.64	0.06	1.25	2.24
PH350	51	0.35	99.57	0.09	0.41	1.53
TB130	30	0	84.10	15.90	0.13	1.61
TB150	49	0.53	98.95	0.53	0.24	1.12
TB230	27	54.18	45.49	0.33	4.47	2.47
TB250	47	1.04	98.60	0.37	0.24	1.18
TB329	27	61.92	34.95	3.13	4.27	9.37
TB320	20	41.67	58.21	0.12	2.78	1.93
TB330	31	3.44	96.43	0.12	0.49	1.65
TB350	50	0	99.79	0.21	0.22	1.18
TB429	29	0	92.21	7*79	0.11	1.25
TB431	30	0	94.87	5.13	0.13	1.26
TB450	(30)	40.81	58.69	0.50	2.36	2.56
TB450	(50)	0	99.92	0.08	0.23	1.26
TB520	20	0	99.72	0.28	0.23	1.19
TB540	40	0.24	99.57	0.18	0.25	1.26
TB550	53	0.50	99.19	0.31	0.29	1.28

(a) Geometric mean

(b) Sorting index

(c) Data loss (DL)



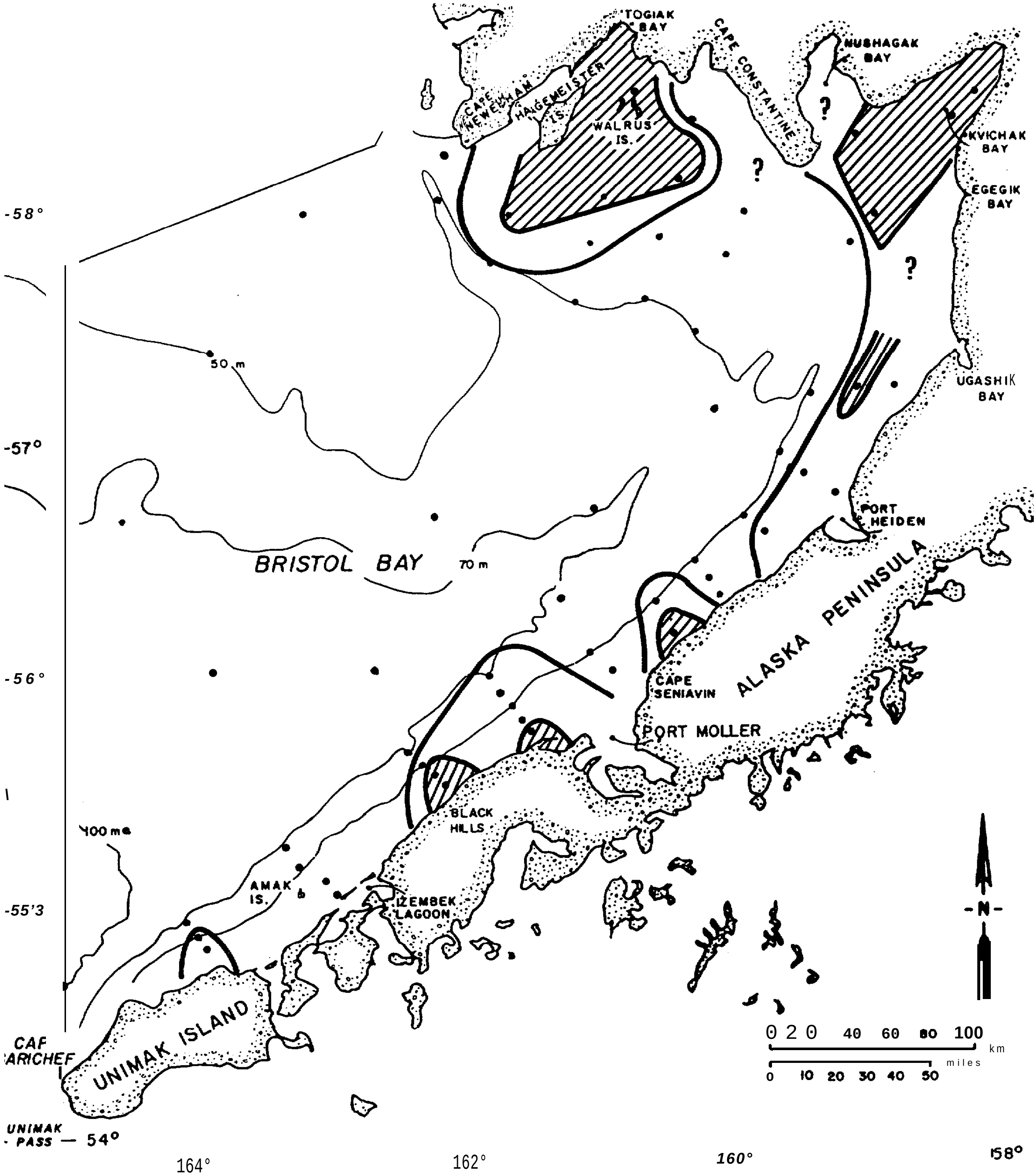
SYMBOL = SAMPLING AREA

A = IL
0 = PM
◘ = BB
● = KB
■ = PH
A = TB

BRISTOL BAY
RED KING CRAB

PERCENTAGE SILT, SAND AND GRAVEL
IN SEDIMENT SAMPLES

FEBRUARY 1984 | FIGURE 3.1-13



• = SEDIMENT SAMPLING STATION

— = >1 % GRAVEL

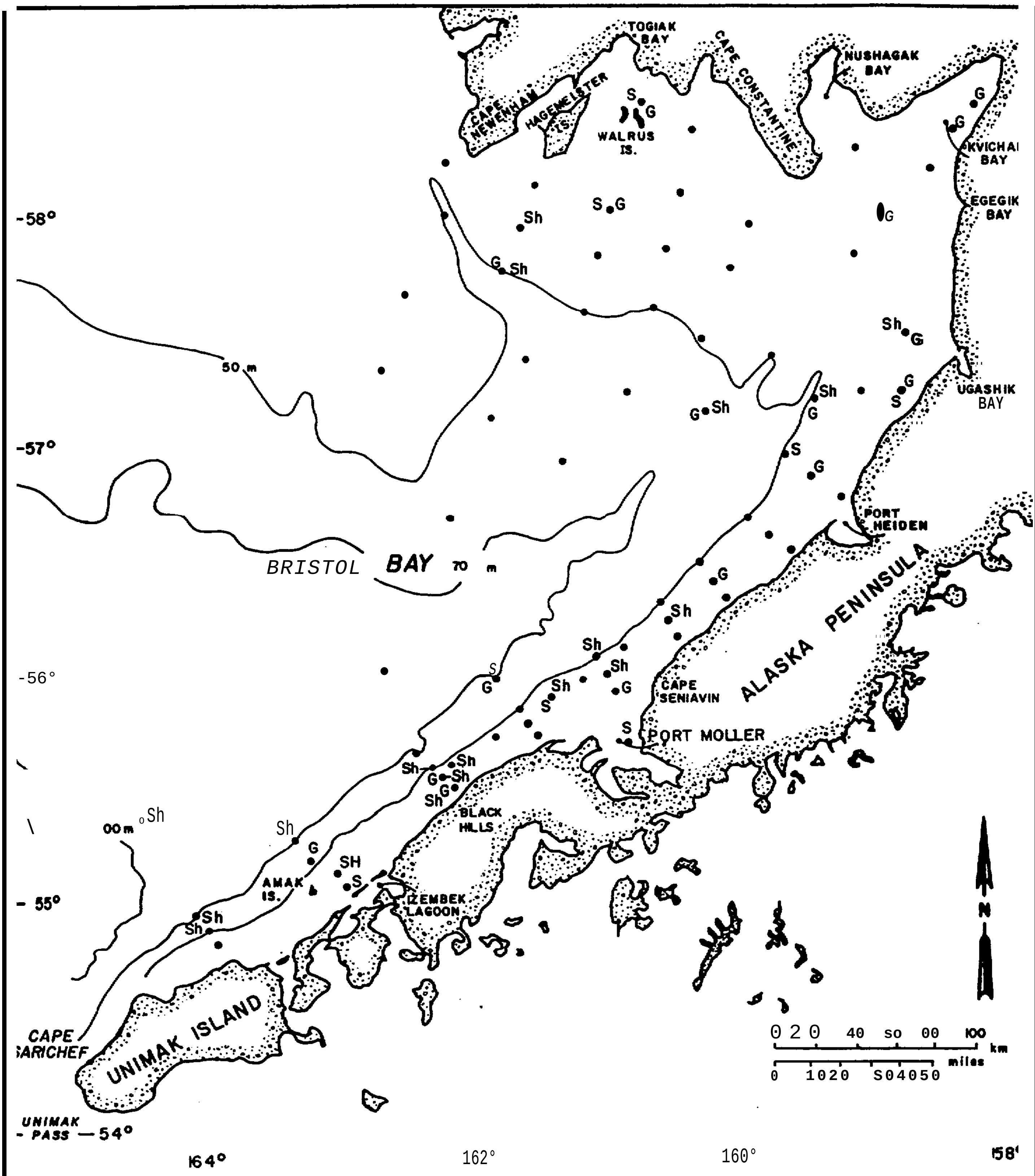
▨ = >10% GRAVEL

? = NO DATA

BRISTOL BAY
RED KING CRAB

PERCENT GRAVEL CONTOURS
IN BRISTOL BAY

FEBRUARY 1984 | FIGURE 3.1-14



G = GRAVEL OR GRAVEL AND COBBLE

S = SAND

Sh = SHELL DEBRIS

BRISTOL BAY
RED KING CRAB

TRAWL SAMPLE OBSERVATIONAL
SUBSTRATE DATA

FEBRUARY 1984 | FIGURE 9.1-16

between Unimak Island and Port Moller, off Port Heiden and off Hagemeister Island in the Togiak Bay area.

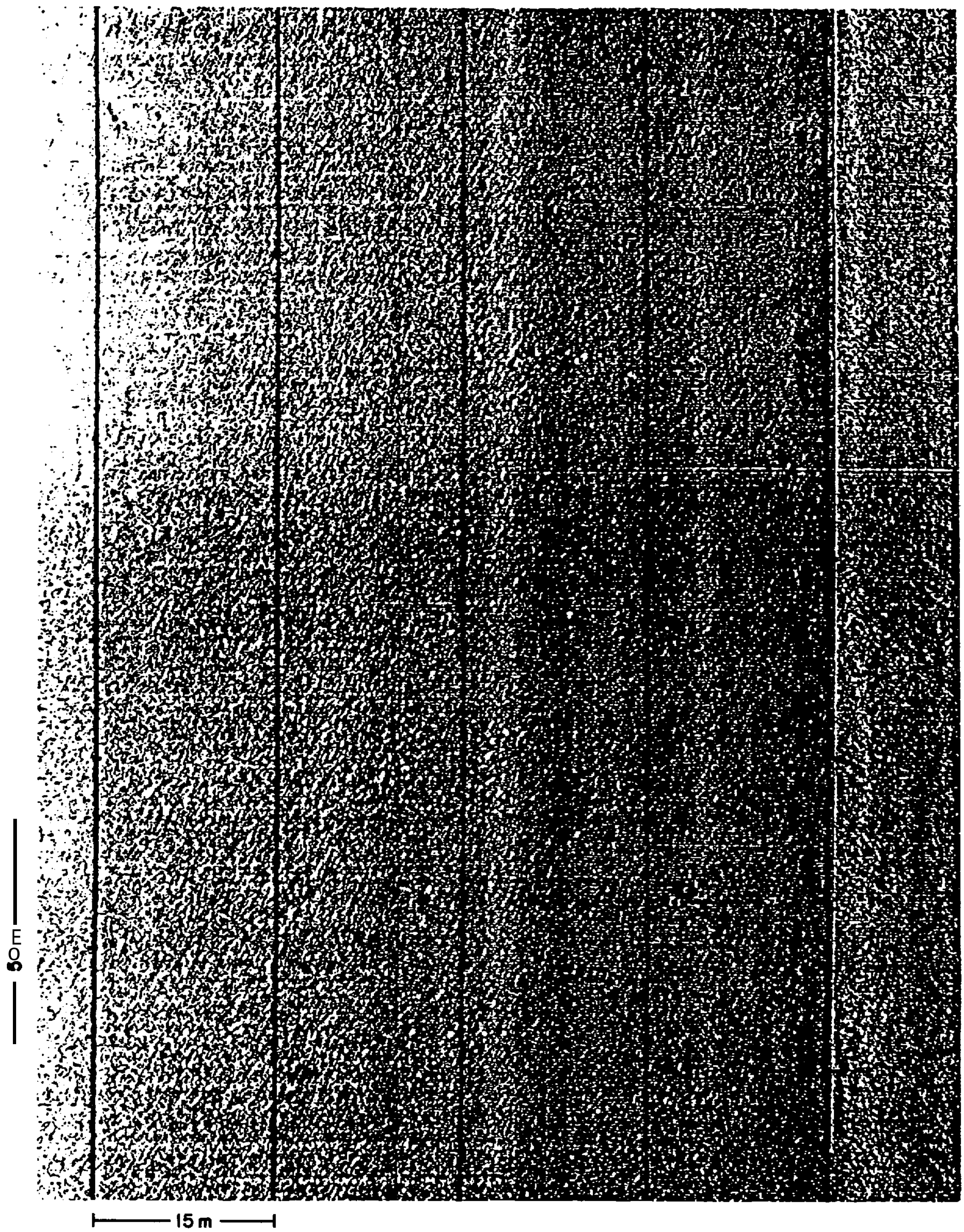
Side Scan Sonar. Side scan sonar surveys were successfully employed in order to discern gravel and cobble substrates from silt and sand substrates. Portions of sonar traces showing silt-sand and gravel-cobble areas are reproduced in Figures 3.1-16 and 3.1-17, respectively. Although the project budget precluded analysis of ground truth samples, subjective observations of Shipek dredges and try net and rock dredge hauls indicated that the samples support these side scan interpretations.

Intensive side scan sonar surveys, each approximately one nautical mile square (3.43 km^2), were conducted at stations PM630 and KB2*4 during cruise 83-5. The Port Moller survey exhibited no discernible heterogeneity in the substrate. The Kvichak Bay survey yielded transects with apparent areas of gravel-cobble such as that shown in Figure 3.1-17. When the transects for the survey were joined and drawn to scale, the gravel-cobble areas emerged as long, narrow beds, oriented approximately parallel to the axis of Kvichak Bay. The beds were 20-30 m wide and between 50 and 800 m long. A graphic representation of the beds in the Kvichak Bay survey is shown in Figure 3.1-18.

3.2 Larval Distribution and Abundance

3.2.1 Horizontal Distribution and Abundance

Distribution. Larval densities along the North Aleutian Shelf from Unimak Island to Port Heiden were very low during all times sampled (late April, late May, mid-June) in 1983 compared to densities recorded for 1982 over the same area. Data from the two week period of about April 23 to May 7 show that larvae were most abundant offshore of Black Hills to western Port Moller (Figure 3.2-l). Larvae were virtually absent in the area from western Unimak Island to Izembek Lagoon, and north of latitude 56°40′ (about Port Moller) to the limit of sampling

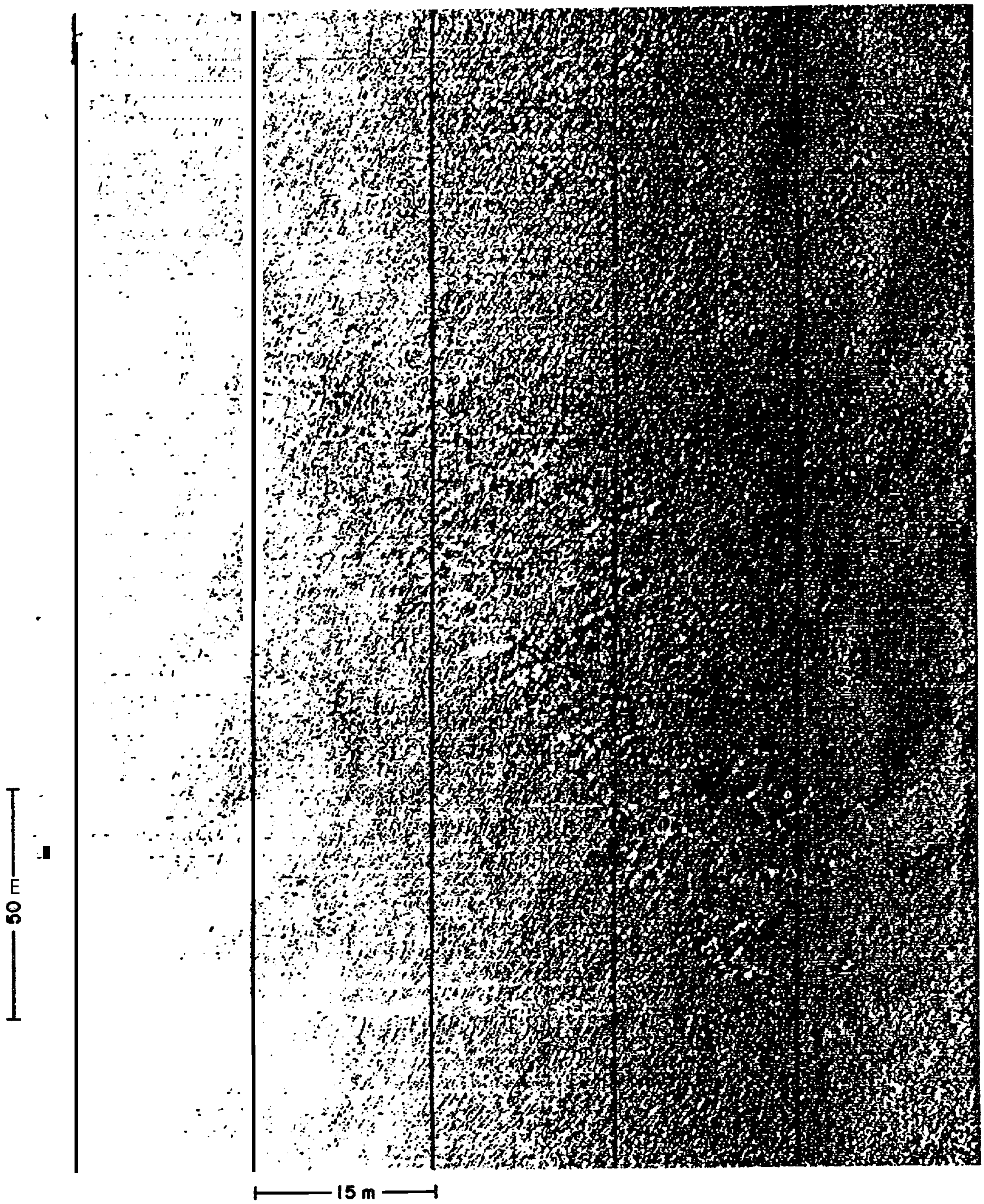


BRISTOL BAY
RED KING CRAB

SIDE-SCAN SONAR TRACE SHOWING HOMOGENEITY INDICATIVE OF SILT-SAND SUBSTRATE

vtn

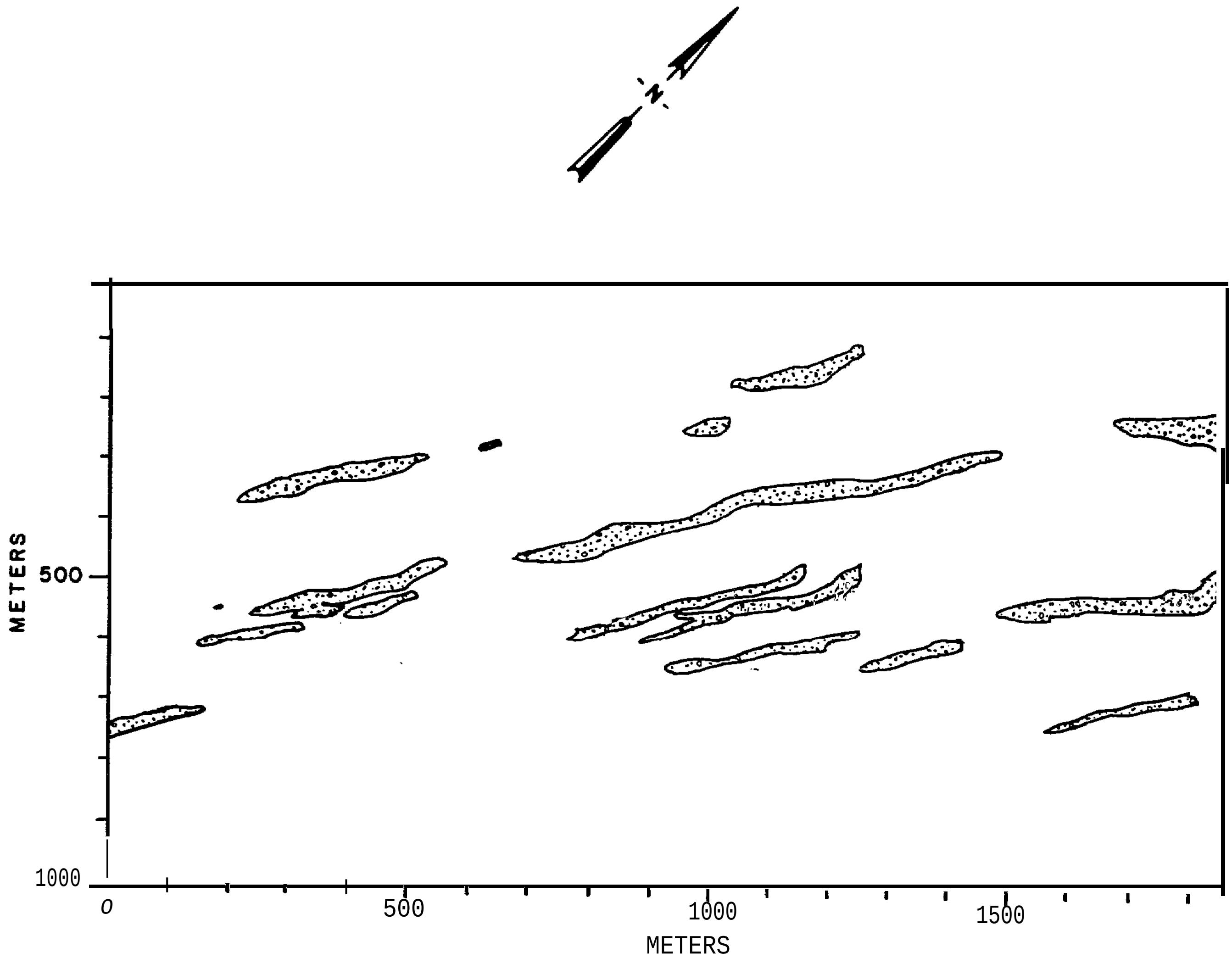
FEBRUARY 1084 | FIGURE **3.1-16**



BRISTOL BAY
RED KING CRAB

SIDE-SCAN SONAR TRACE
SHOWING HETEROGENEITY
INDICATIVE OF GRAVEL-COBBLE
SUBSTRATE

FEBRUARY 1984 FIGURE 3.1-17



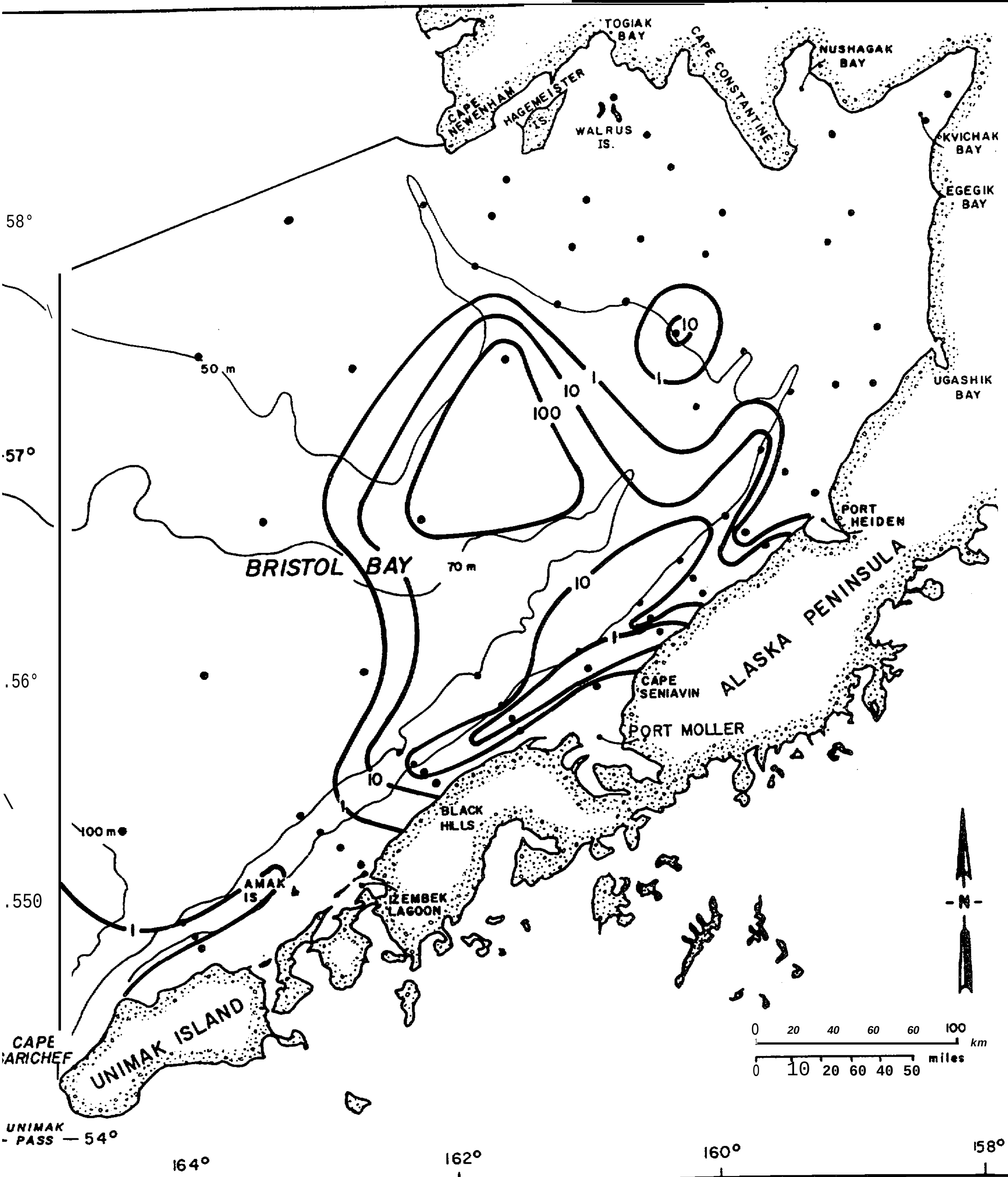
= APPARENT SILT-SAND SUBSTRATE

= APPARENT GRAVEL-COBBLE SUBSTRATE

(LOCATION SHOWN IN FIGURE 2.1-5)

BRISTOL BAY
RED KING CRAB
APPARENT SIZE AND ORIENTATION OF GRAVEL-COBBLE BEDS IN KVICHAK BAY

FEBRUARY 1984 | FIGURE 3.1-18



● = SAMPLING STATION

— 10 — = NUMBERS OF RED KING CRAB LARVAE PER 100 m^2

BRISTOL BAY
RED KING CRAB

CRUISE 83-1
LARVAL RED KING CRAB DISTRIBUTION

vtn

FEBRUARY 1084 FIGURE 3.2-1

along the coast from Cape Newenham into Kvichak Bay. Greatest densities recorded were just over 1,000 larvae per 100 m^2 along the 50 m isobath in subareas IL and PM. Mean densities in these areas were still relatively low, 114 $\pm$ 311 and 137 $\pm$ 242 per 100 m^2, respectively, and elsewhere ranged from zero larvae in all of the Kvichak subarea to a mean of 133 per 100 m^2 in Inner Bristol Bay (Table 3.2-l). Densities. were uniformly lowest nearshore (<50 m) throughout the entire study area.

Collections made during the first cruise in April 1983 apparently intercepted the commencement of hatchout and, thus, low densities could reflect a larval population not yet to full numerical strength. However, this possibility was not supported by subsequent sampling in the region from Unimak Island to Cape Seniavin during late May and mid-June. A series of zooplankton samples collected about May 27, 1983 (at the end of the Pribilof Island cruise) showed that larval abundance had increased off Port Moller, where highest densities were 1,175 to 3,300 larvae per 100 m^2 and averaged 902 larvae per 100 m^2 (Table 3.2-l). From there heading along the 50 m isobath to the southwest, densities were only a few hundred larvae per 100 m^2.

Nearshore larval density was extremely low in mid-June 1983 from Unimak Island through Cape Seniavin with mean values of about 230 larvae per 100 m2 (Table 3.2-1, Figure 3.2-2). The moderate larval densities found off Black Hills to Port Moller in April and May had decreased by June due to either local mortality and/or transport to the northeast in nearshore currents (Armstrong, et al. 1983b; Haynes 1974). Further, larvae were scarce nearshore in water less than 50 m throughout the remaining survey area from Port Moller northeast to Kvichak Bay, then west to Cape Newenham. Instead, larvae were densest at stations between 50 to 70 m within or adjacent to subarea IB, Inner Bristol Bay (Figure 3.2-2). All nearshore areas at this time had mean abundances of about 200 to 400 larvae per 100 m^2 whereas the mean for subarea IL was 2,135 per 100 m^2 (Table 3.2-1). It should be noted that several of the

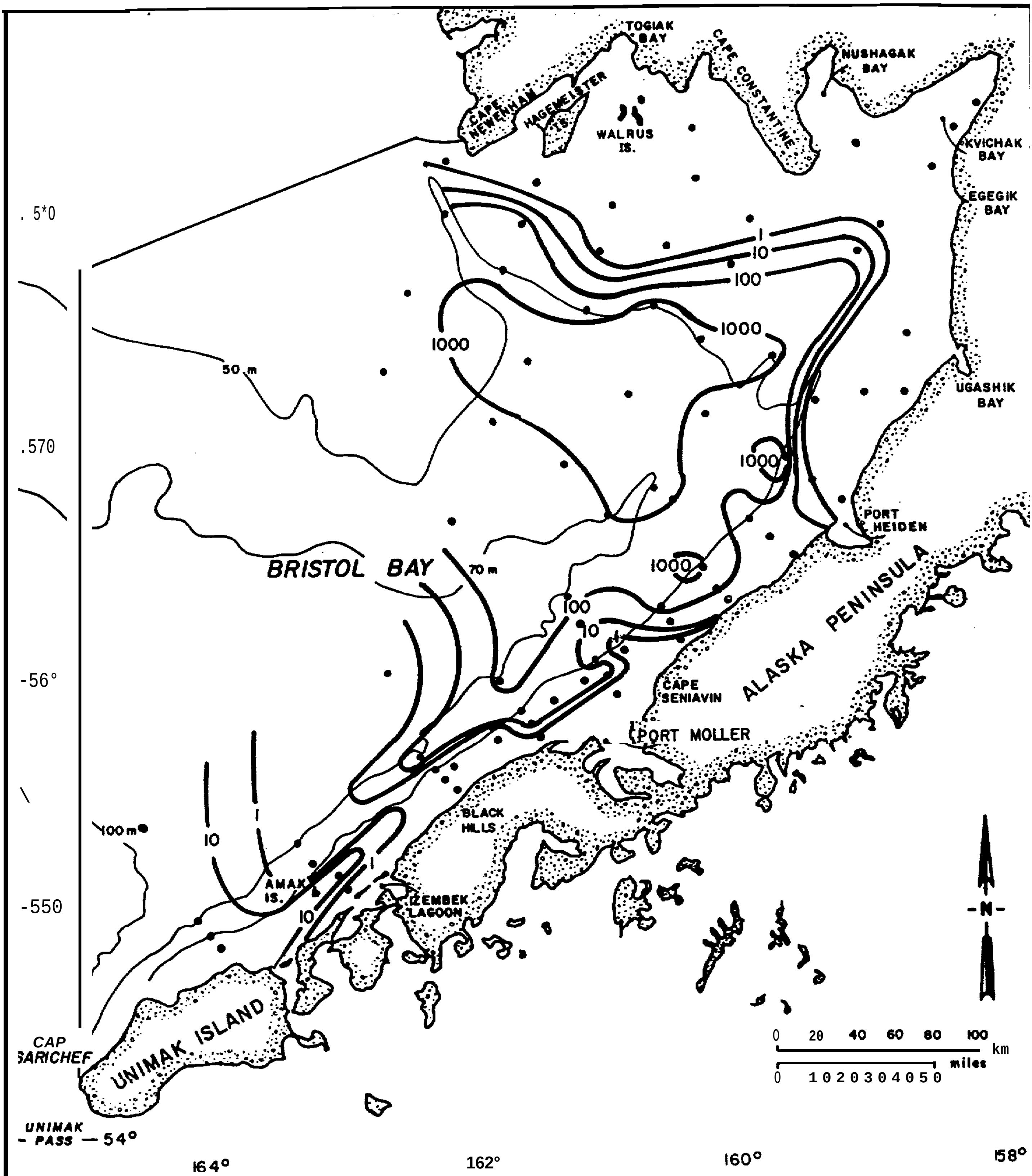
TABLE 3.2-1

MEAN LARVAL RED KING CRAB DENSITIES BY CRUISE AND SUBAREA[a]

Subarea	Cruise 83-1 (April-May)	Cruise 83-2 (May)	Cruise 83-3 (June)
OB	2.6 + 6.9[b] (n = 8)	139+ 119 (n = 6)	75.5 (n = 1)
IB	133 + 174 (n = 6)	902 + 982 (n = 8)	2134 + 3137 (n = 11)
IL	114 + 311 (n = 12)		43+ 72.5 (n = 12)
PM	137 + 242 (n = 18)		231 + 404 (n = 22)
PH	32.8+ 60.4 (n = 10)		208 + 530.5 (n = 9)
KB	0 (n = 6)		389 + 987 (n = 7)
TB	2.0 + 7.5 (n = 15)		458 + 760 (n = 14)

(a) Arithmetic'means and standard deviations are given in this table to facilitate comparison with other studies; it is not suggested that normal statistics are applicable to non-transformed data.

(b)Larvae per 100 m2.



• = SAMPLING STATION

—10- = NUMBERS OF RED KING CRAB LARVAE PER 100 m²

BRISTOL BAY
RED KING CRAB

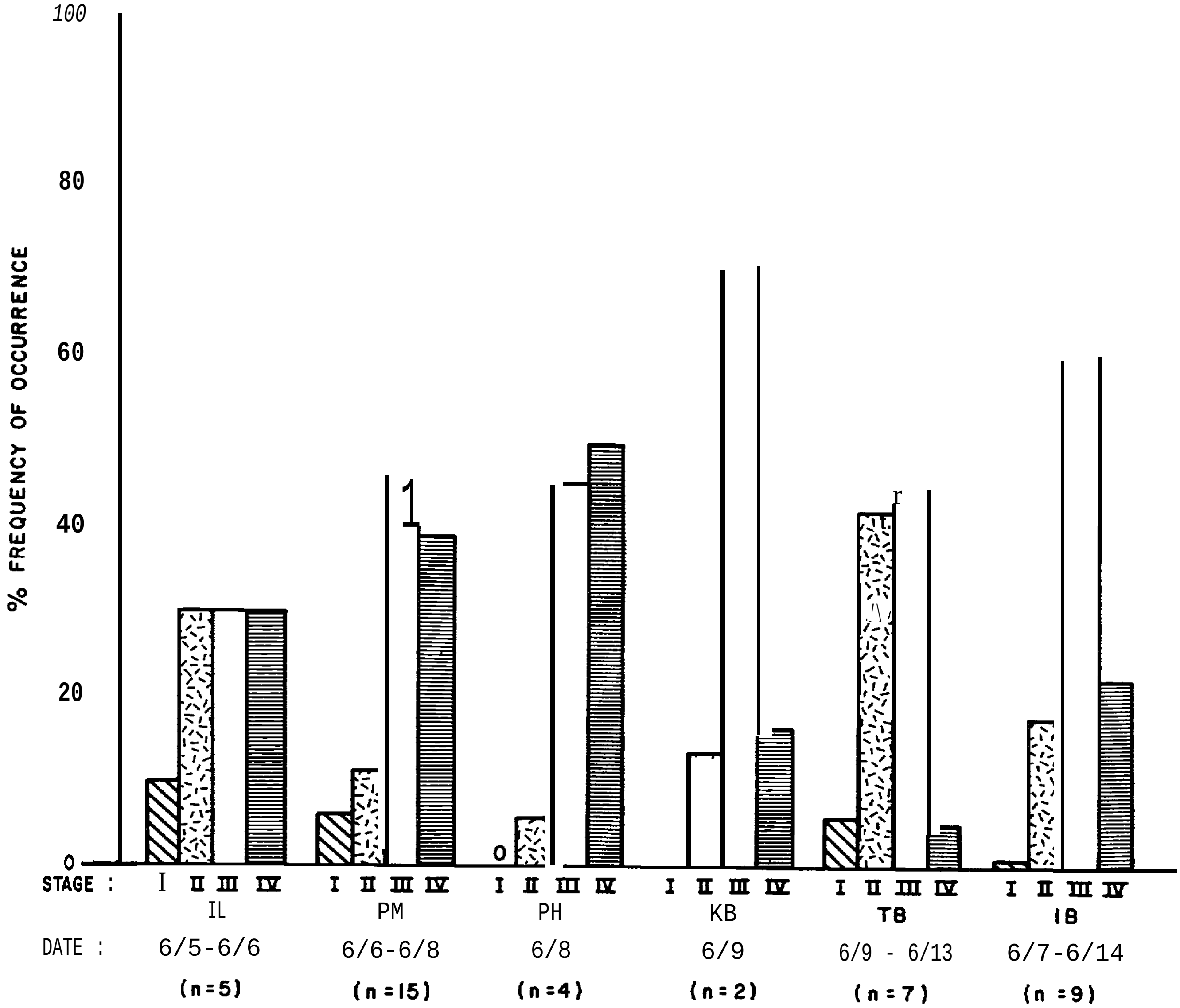
CRUISE 83-3
LARVAL RED KING CRAB
DISTRIBUTION

FEBRUARY 1984 FIGURE 3.2-2

stations in this area where larval king crab were abundant were also rich in phytoplankton; so much so that nets apparently clogged as evidenced by very low volumes filtered per unit time compared to other stations of comparable depth. Resultant calculations of high larval densities reflect either the actual at the time in Inner Bristol Bay, or possibly inflated values caused by inaccurate estimates of volume filtered.

Stage IV zoeae were the most advanced larvae collected during the second cruise through June 14. No megalops larvae were found in June 1983, although they were present between Unimak Island and Cape Seniavin at the same time in 1982 (Armstrong, et al. 1983b). No king crab larval stages were found in zooplankton samples collected in mid-September 1983. All larvae had apparently metamorphosed by this date and, as discussed in Section 3.4 on juveniles, young-of-the-year crab were caught at this time in areas largely outside the regions of high larval abundance.

Date of l-latch. The first zooplankton samples were collected during a sweep along the nearshore NAS from Unimak Island to Kvichak Bay in mid-April 1983. Few larvae were found during that first pass of the area and additional samples were taken as the ship left Bristol Bay between May 1 and 5. More red king crab larvae were found in this second group of samples, indicating that a substantial part of the 1983 hatch occurred in the last week of April through the first week of May. Hatch did not apparently continue for a prolonged period throughout the nearshore range of the population because: 1) average densities in April, May and June did not increase substantially (Table 3.2-1) in subareas IL and PM; and 2) zoeal stage frequency over these months showed a shift to later stages consistent with the molting schedule of a single, dominant cohort. There was no apparent and substantial hatch that occurred in late May and early June in subareas IL, PM and PH based on stage frequencies (Figure 3.2-3). Frequency of occurrence of larval stages in samples taken from eastern Unimak Island to Port Heiden over a



FREQUENCY OF OCCURRENCE CALCULATED FROM GEOMETRIC MEANS

BRISTOL BAY
RED KING CRAB

LARVAL STAGE FREQUENCY
BY SUBAREA DURING JUNE 1983

FEBRUARY 1964 | FIGURE 3.2-3

three-day period in June showed rather similar proportions; from 60 to 90 percent of the larvae were S111 and SIV.

Peak hatching may have occurred a week or two later in other parts of the species range encompassed by strata for Kvichak and Togiak Bay and Inner Bristol Bay (Figure 3.2-3). Frequency of occurrence of larval stages in these strata showed substantially fewer SIV and more S111 larvae, and in the Togiak strata (TB) up to 45 percent S11. Particularly in the case of Togiak, stations with high proportions of earlier S11 larvae were those near the 50 m isobath on the edge of the Inner Bristol Bay (IB) stratum.

The possibility that colder water temperatures may have caused later hatchout in the area of Bristol Bay between 50 to 70 m is suggested by data for June 1983. Although near-surface temperatures were essentially the same in that region as elsewhere in June (5° to 7°C, Figure 3.1-8), bottom water temperatures were still 3° to 4° C (Figure 3.1-11), having been about 1°C in April (Figure 3.1-10). An ovigerous female caught in the area during the June cruise had eyed eggs still unhatched in early summer. Regional and interannual differences in bottom water temperature may significantly affect the rate of embryonic development in the egg and, in turn, the appropriate time of hatch each year (Armstrong, et al . 1983 b). The occurrence of many S11 larvae in the offshore area of Togiak in mid-June (stations collected June 12-14) indicates that they had hatched in the last week of May (based on the molt frequency data of Armstrong, et al. 1983), some three weeks later than the cohort off Port Moller.

Correlation to Physical Factors. Larval horizontal distribution and abundance were analyzed" for relationships with station depth, salinity and temperature at 10 m, time of day when collected, and Julian date. Station depth yielded the sole significant correlation coefficient ($r=^{+}0.344$; 171 degrees of freedom), explaining only 11.8 percent of the variability in the data set. Residuals indicated the correlation resulted from the apparent concentration of crab larvae along the 50 m isobath. Addition of the other independent variables in multiple regressions did not meet criteria for significance.

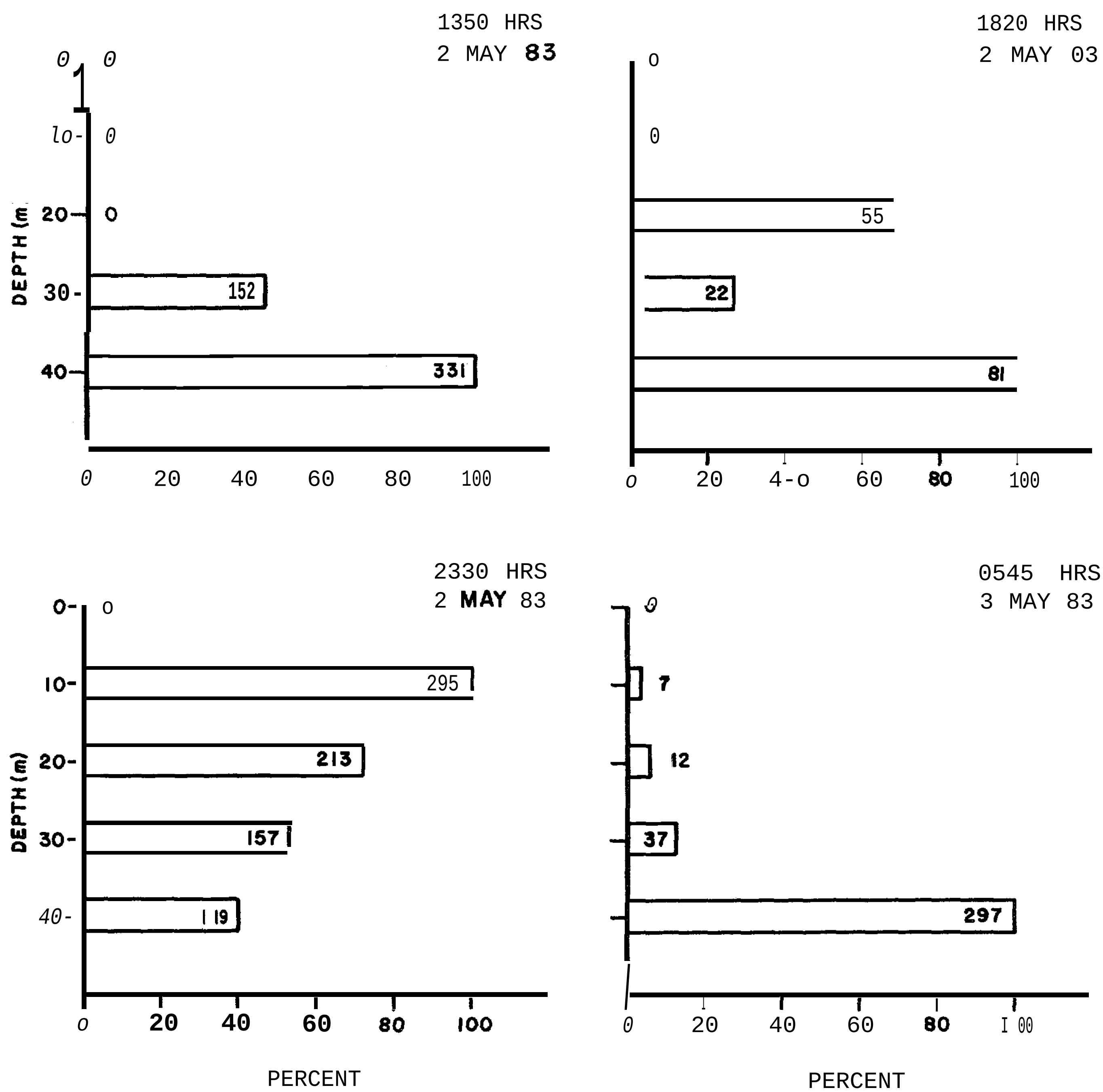
3.2.2 Vertical Distribution

During cruise 83-1 (April-May), a diel series of horizontal plankton tows was conducted at station PM350. The 40, 30, 20 and 10 meter samples were collected with a Tucker trawl; the surface sample was collected with a Sameoto Neuston sampler. The sampling was conducted at local noon, dusk, midnight and sunrise. The resulting larval red king crab densities are shown in Figure 3.2-4, and show strong evidence of diel vertical migration. No larvae were collected at the surface. The noon and midnight samples exhibit the greatest difference in vertical distribution; the dusk and dawn samples are intermediates.

During cruise 83-3 (June), a single vertical series of horizontal tows, 0-50 m, was conducted with the Tucker trawl. The larval red king crab densities are presented in Figure 3.2-5. This figure also indicates the zoeal stage distribution of the samples. The results do not show any difference in vertical distribution between stages. The two larger samples, from 20 and 50 m depth, contained very similar proportions of zoeal stages 2, 3 and 4.

3.3 Larval Development and Growth

The most appropriate time series by which to measure larval development was collected in the Port Moller subarea. Samples were collected at six times: 23-25 April; 1-2 May; 27 May; 6-8 June; 14-16 June; and 11-13 September (Table 3.3-1). Larvae were present from April until mid-June. First stage zoeae, though present until mid-June, were most abundant in early May. The next three zoeal stages were sequentially predominant over the second through fourth visits off Port Moller. This may be seen in Figure 3.3-1, which has averaged the results from the two visits



210

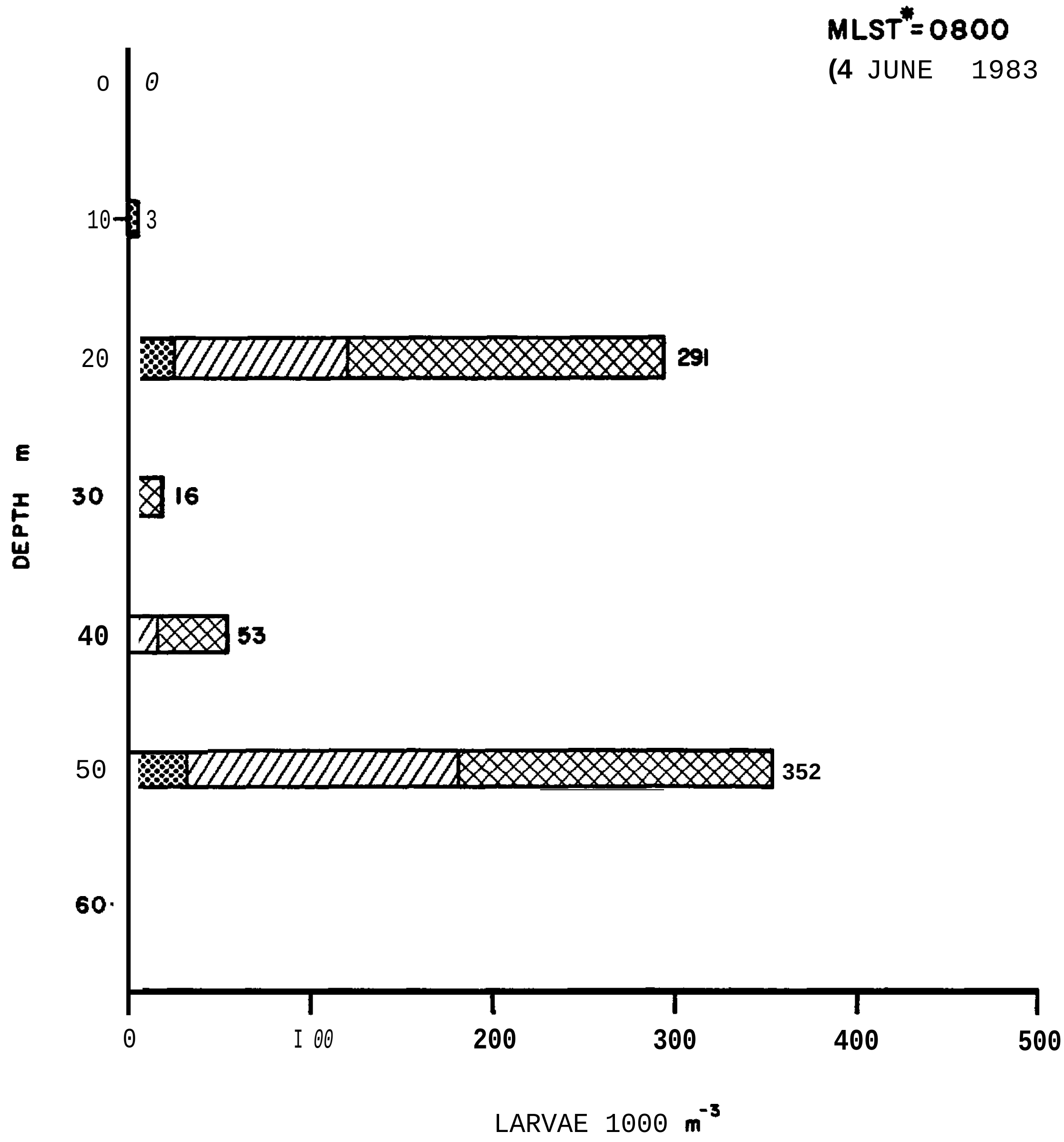
= Percent of Max. Density

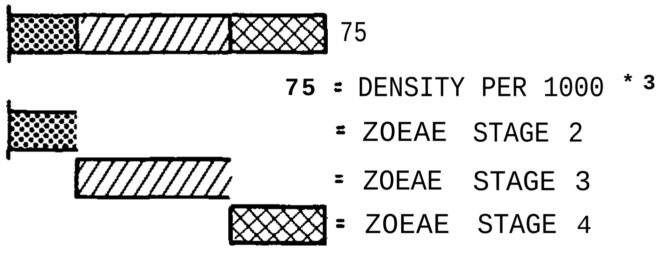
210 = Actual Density per 1,000 m^3

BRISTOL BAY
RED KING CRAB

DIEL VERTICAL DISTRIBUTION OF
RED KING CRAB LARVAE

FEBRUARY 1984 | FIGURE 3.2-4





*MLST = MEAN LOCAL STANDARD TIME

BRISTOL BAY
RED KING CRAB

VERTICAL DISTRIBUTION OF RED KING CRAB ZOEAE STAGES 2, 3 AND 4

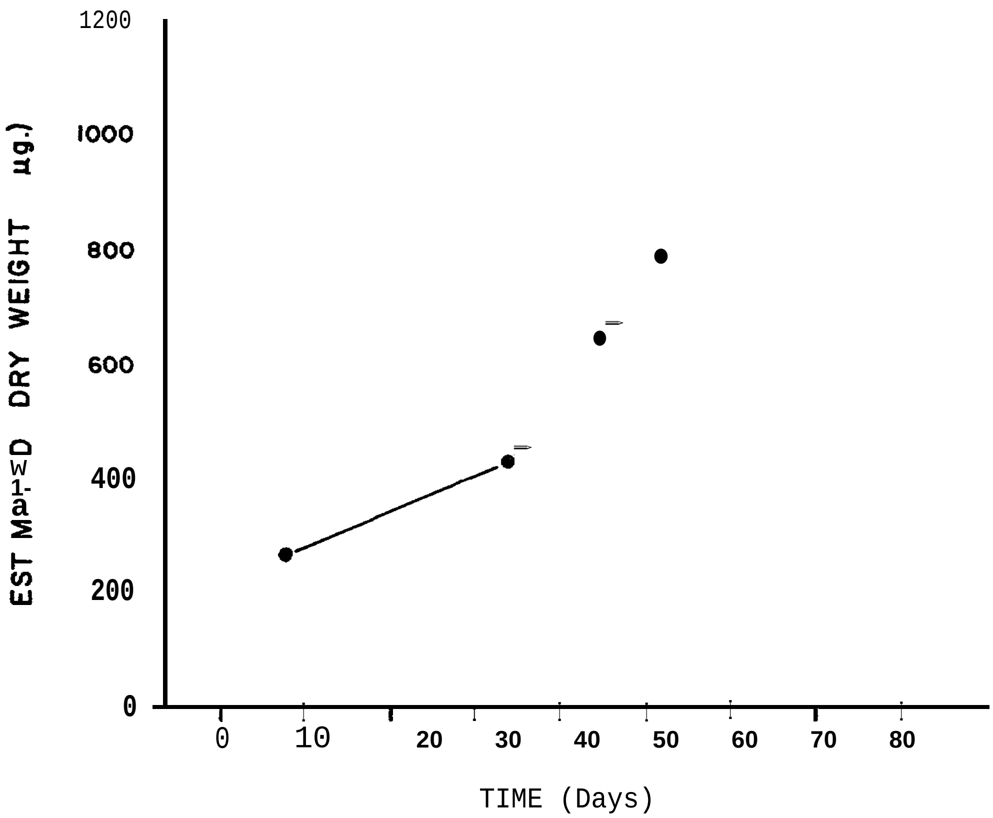
FEBRUARY 1984 | FIGURE 3.2-5

TABLE 3.3-1

GEOMETRIC MEAN DENSITIES OF LARVAL RED KING CRAB
IN THE PORT MOLLER SUBAREA BY DEVELOPMENTAL STAGE

	Growth Stage					
Sampling Period	1	2	3	4	5	Total
23-25 April	0.39[a]	-				0.39
1-2 May	312.28	0.39				312.67
27 May	10.91	195.53	15.42	0.46	-	222.32
6-8 June	0.01	0.14	0.48	0.23	-	0.86
14-16 June	0.02	0.07	0.23	0.12	-	3.77
11-13 September						

(a) Numbers per 100 m^2 (area weighted)



BRISTOL BAY
RED KING CRAB

ESTIMATED GROWTH RATE OF
LARVAL RED KING CRAB
APRIL - JUNE 1983

FEBRUARY 1984

FIGURE 3.3-1

during the June cruise (83-3). No megalopae (glaucothoe) were collected during this study.

Individual larval growth was substantial between late April and mid-June. The estimated daily individual growth rate rose from 4.58 ug dry weight per day between late April and mid-May to 18.74 ug dry weight per day between late May and mid-June (Figure 3.3-1). This occurred while the individual zoeae were increasing from an estimated individual mean of 265 ug to 878 ug dry weight.

3.4 Post-larval Size and Age Distribution

Cruise 83-1 (18 April - 7 May 1983). In April and May 1983, 131 red king crabs were collected from 21 stations (Table 3.4-1). The population was composed of 81 (62%) males, 43 (33%) juvenile females, and seven (5%) adult females, whose sizes ranged from 4-133 mm carapace length. Using Weber's age criteria (Weber 1967) only 7.6 percent of all crabs collected during April and May were one year-old. An additional 10 crabs (7 .5%) were less than age 1 (0+ or 1982 YOY). A total of 18 1+ year-old (15-28 mm) and two 2 year-old crabs was found. Only two crabs were found in the 2+ age category. A total of 22 age 3 (50-67 mm) crabs were encountered; age 3+ and age 4 crabs numbered 11 and 10, respectively. Eight adult females were part of the age 4++ crabs.

The male:female ratios at ages 1, 2, 3, 4 and 4++ were 4:1, 2:1, 1:1, 0.6:1, and 1.3:1, respectively. The male:female ratio for all juvenile sizes through age 4 was 1.8:1 (Table 3.4-l).

Cruise 83-3 (2-17 June 1983). A total of 137 red king crabs was collected during the June cruises (Table 3.4-2). The crab population composition was 73 (53%) males, 49 (36%) immature females, 7 (5%) unidentified sex and 8 (6%) adult females. The sizes ranged from 3-126 mm carapace length. Only five age 1 crabs were collected. Thirteen crabs were younger than one year of age (1982 YOY). A total of 21 age

TABLE 3.4-1

NUMBER OF POST LARVAL RED KING CRAB BY SAMPLING LOCATION, SIZE AND AGE FROM CRUISE 83-1

Station	0+(a) <8(b)	1 9-14	1+ 15-28	2 29-41	2+ 42-49	3 50-67	3+ 68-73	4 74-82	4++ 82-133	Tots?s
PM820	5	1								6
PM250	1				1	1	1			4
PM230	3									3
KB2*4		7	14	2	1	2			2	28
KB2*0		1								1
TB329		1	1							2
TB230	1									1
IL430			1							1
PM730			1							1
PM620			1							1
TB550						8	1			9
TB431								1	1	2
TB350						8		1	4	13
BB557						3	9	7	8	27
BB770								1	5	6
IL160									15	15
PM370									2	2
BB760									1	1
KB250									1	1
TB250									6	6
BB450									1	1
Totals	10	10	18	2	2	22	11	10	46	131
%	7.6	7.6	13.7	1.5	1.5	16.8	8.4	7.6	35.1	100.0
Males	7	8	16	2	1	11	7	3	26	81
Females	3	2	2	0	1	11	4	7	20	50

(a) Age in years

(b) Carapace length in mm

TABLE 3.4-2

NUMBER OF POST LARVAL RED KING CRAB BY SAMPLING LOCATION, SIZE AND AGE FROM CRUISE 83-3 (JUNE)

Station	0+(a) <8(b)	1 9-14	1+ 15-28	2 29-41	2+ 42-49	3 50-67	3+ 68-73	4 74-82	4++ 83-126	Totals
PM350	1									1
PM650	1					2			1	4
PM930	2									2
PM350	3		1			10		1		15
TB329	1									1
IL430	1									1
PH230	2									2
PH250	2									2
KB2*0		1	6							7
KB2*2		3	4							7
KB2*4		1	1							2
KB2*6			7							7
KB2*9			1							1
KB150			1							1
PM730					1	1				2
PM620						1				1
TB550						10	4	4	5	23
BB557						7	4	8	4	23
TB450							1	1	1	3
BB770							1	1	4	6
BB665							2	2	4	8
TB350								1	6	7
BB670								1		1
PM670									3	3
KB250									1	1
TB330									2	2
TB250									2	2
BB450									1	1
BB555									1	1
BB760									2	2
BB560									1	1
Totals	13	5	21	0	1	31	12	19	38	140
%	9.3	3.6	15.0	0	0.7	22.1	8.6	12.6	27.1	100.0
Males	2	2	12	0	1	18	5	13	20	73
Females	1	3	9	0	0	13	7	6	18	57
Unid.	10	0	0	0	0	0	0	0	0	10

(a) Age in years

(b) Carapace length inmm

1+ crabs were found, no age 2 crabs and only one age 2+ crab was encountered. Age 3, age 3+ and age 4 crabs totaled 31, 12 and 19, respectively. A total of 38 age 4++ crabs was found, including eight adult females.

The male:female ratios at ages 1, 3, 4 and 4++ were 0.67:1, 1.4:1, 2.2:1 and 1.1:1, respectively. No age 2 crabs were found. The total male: female ratio for all juveniles through age 4 was 1.4:1 (Table 3.4-2).

Cruise 83-5 (9-23 September 1983). Epibenthic sampling for king crab in September yielded 184 crabs collected at 13 stations (Table 3.4-3). The population was composed of 79 (43%) males, 70 (38%) immature females, 35 (17%) crabs of unidentified sex and 3 (2%) adult females. The crabs sampled during September measured from 3-117 mm carapace length. True young-of-the-year crabs (3-8 mm) dominated, yielding 73% (n=134) of the catch. Most of the young-of-the-year crabs (95%) were 4-5 mm. Age 1 crabs totaled 24; age 1+ crabs totaled 24. Crabs belonging to age classes 2, 2+, 3, and 4 were not encountered. Only one crab was found in the age 3+ class. Among the five crabs over four years old (age 4++), three were adult females.

The male:female ratios at ages 1 and 4++ were 0.6:1 and 0.25:1, respectively. The male:female ratio of all juvenile crabs through age 4 was 1.1:1 (Table 3.4-3).

3.5 Juvenile Distribution and Abundance

The number of epifaunal samples and the number of stations sampled per cruise are presented by sampling subarea in Table 3.5-1. The distributions of samples by gear type are presented in Figures 3.5-1 through 3.5-3 and Appendix B. The inner and outer Bristol Bay (BB) subareas were sampled primarily with the trynet; the Kvichak Bay (KB) subarea was sampled primarily with the rock dredge. The remaining subareas were sampled with both gear types, although the trynet was generally more often used.

TABLE 3.4-3

NUMBER OF POST LARVAL RED KING CRAB BY SAMPLING LOCATION, SIZE AND AGE FROM CRUISE 83-5 (SEPTEMBER 1983)

	YOY[a]	1	1+	2	2+	3	3+	4	4++	
Station	<8[b]	9-14	15-28	29-41	42-49	50-67	68-73	74-82	83-117	Totals
KB2*4	79		1							80
PH230	28	20	11							59
PH250	2									2
PH350	7									7
PM830	4									4
PH130	1									1
KB250	13									13
PM820		1	2							3
PM010		3								3
KB2*1			2							2
PM320			8							8
TB250							1		1	2
BB770									2	2
PM670									1	1
PM370									1	1
Totals	134	24	24	0	0	0	1	0	5	188
%	71.3	12.8	12.8	0	0	0	0.5	0	2.7	100.0
Males	58	7	13	0	0	0	0	0	1	79
Females	46	12	10	0	0	0	1	0	4	73
Unid.	30	5	0	0	0	0	0	0	0	35

(a) Age in years

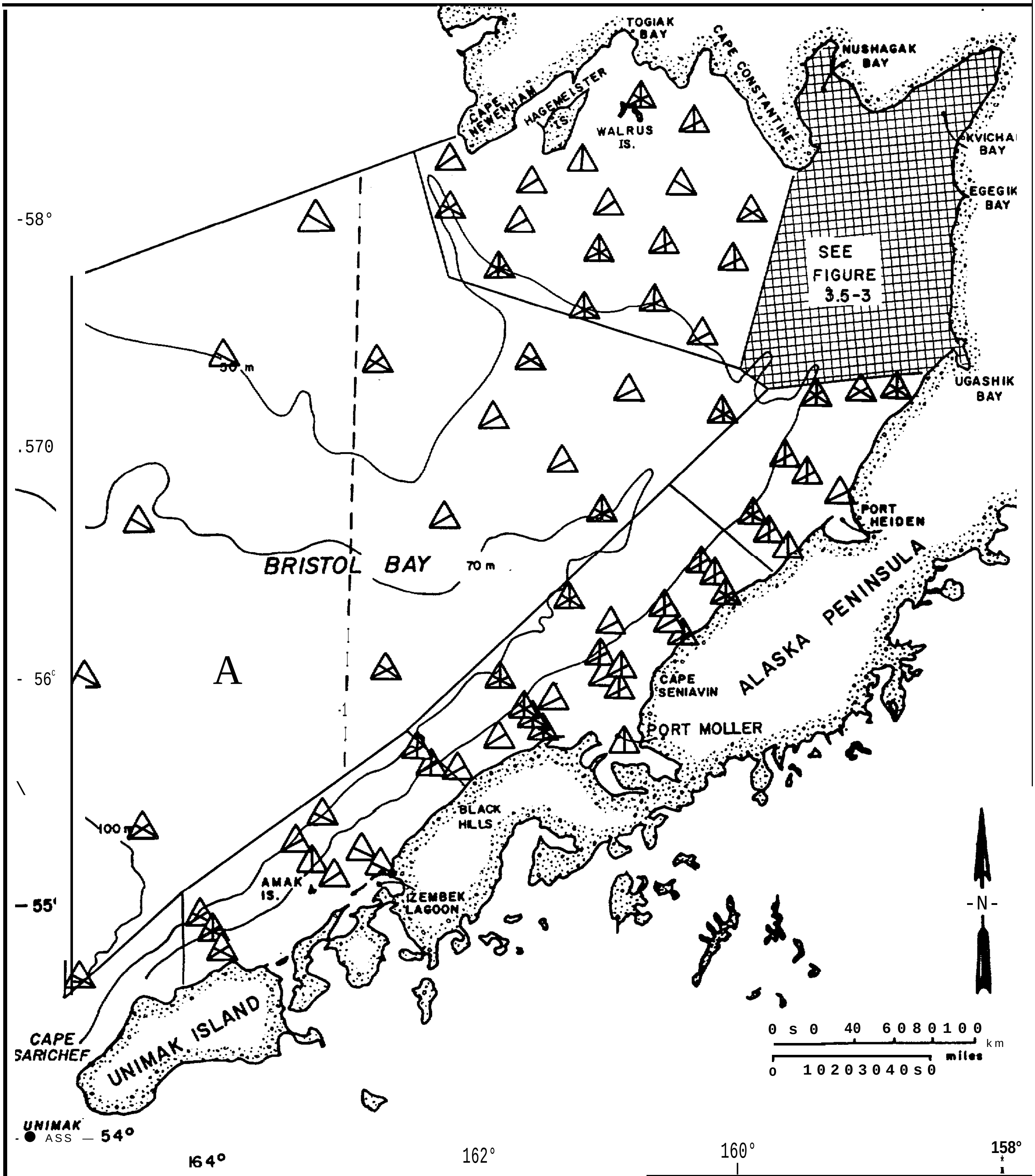
(b) Carapace length in mm

TABLE 3.5-1

SUMMARY OF EPIFAUNAL SAMPLES PER STATION BY SAMPLING SUBAREA DURING 1983

Cruise	BB	IL	PM	PH	KB	TB	Total
83-1:Apr-May	17/13[a]	12/10	20/14	9/8	12/7	17/15	87/67
83-3:June	11/10	13/11	30/23	13/8	22/14	21/16	90/82
83-5:Sept	2/2	7/7	20/15	8/8	12/6	10/10	54/48
Total	30/15	32/28	70/52	30/24	46/27	48/41	

(a) Fraction = Number of epifaunal samples/Number of stations sampled



A = CRUISE 83-1

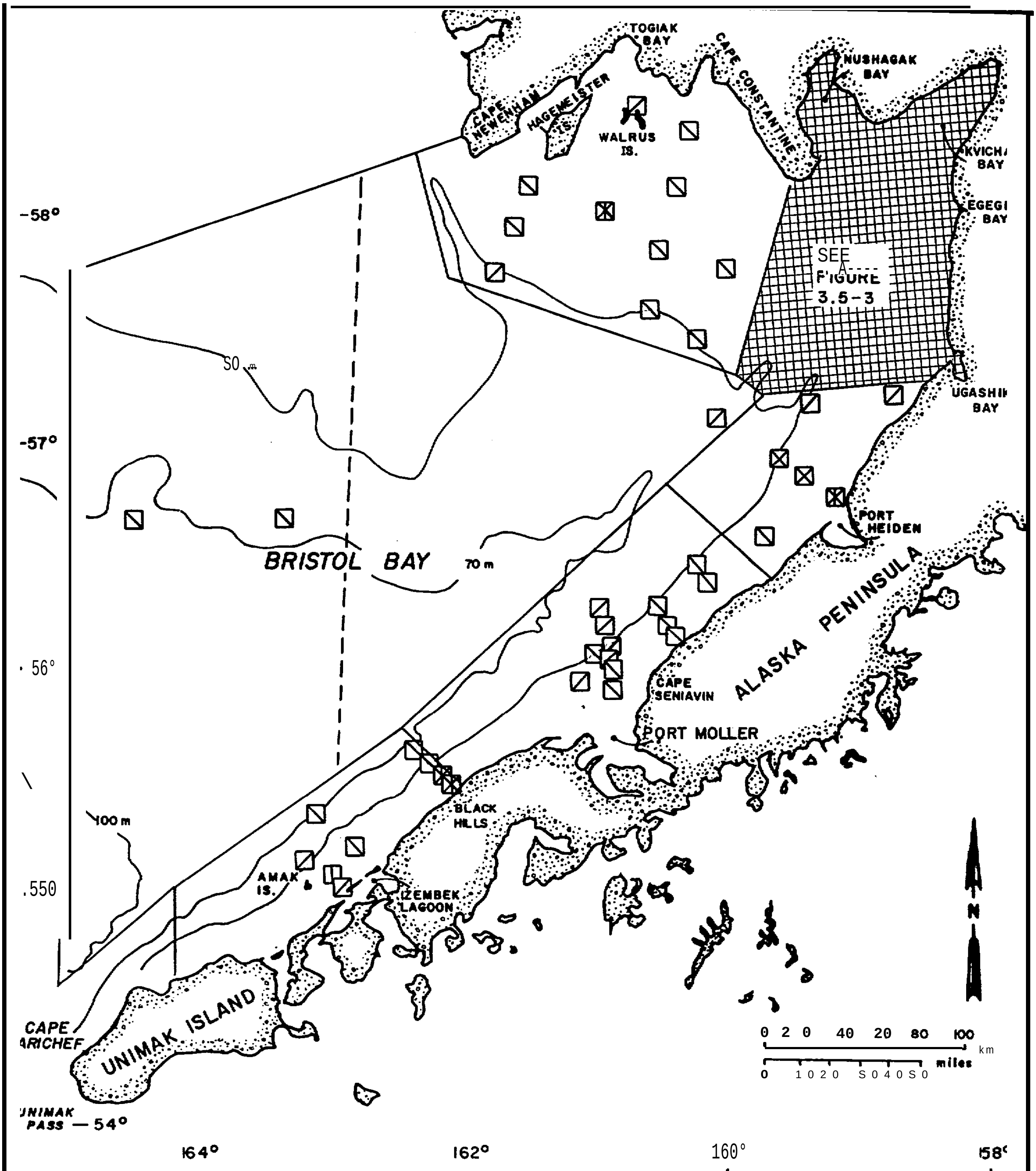
△ = CRUISE 83-3

A = CRUISE 83-5

BRISTOL BAY
RED KING CRAB

TRYNET SAMPLING STATIONS
BY CRUISE

FEBRUARY 1084 | FIGURE 3. S-1



= CRUISE 83- I

= CRUISE 83-3

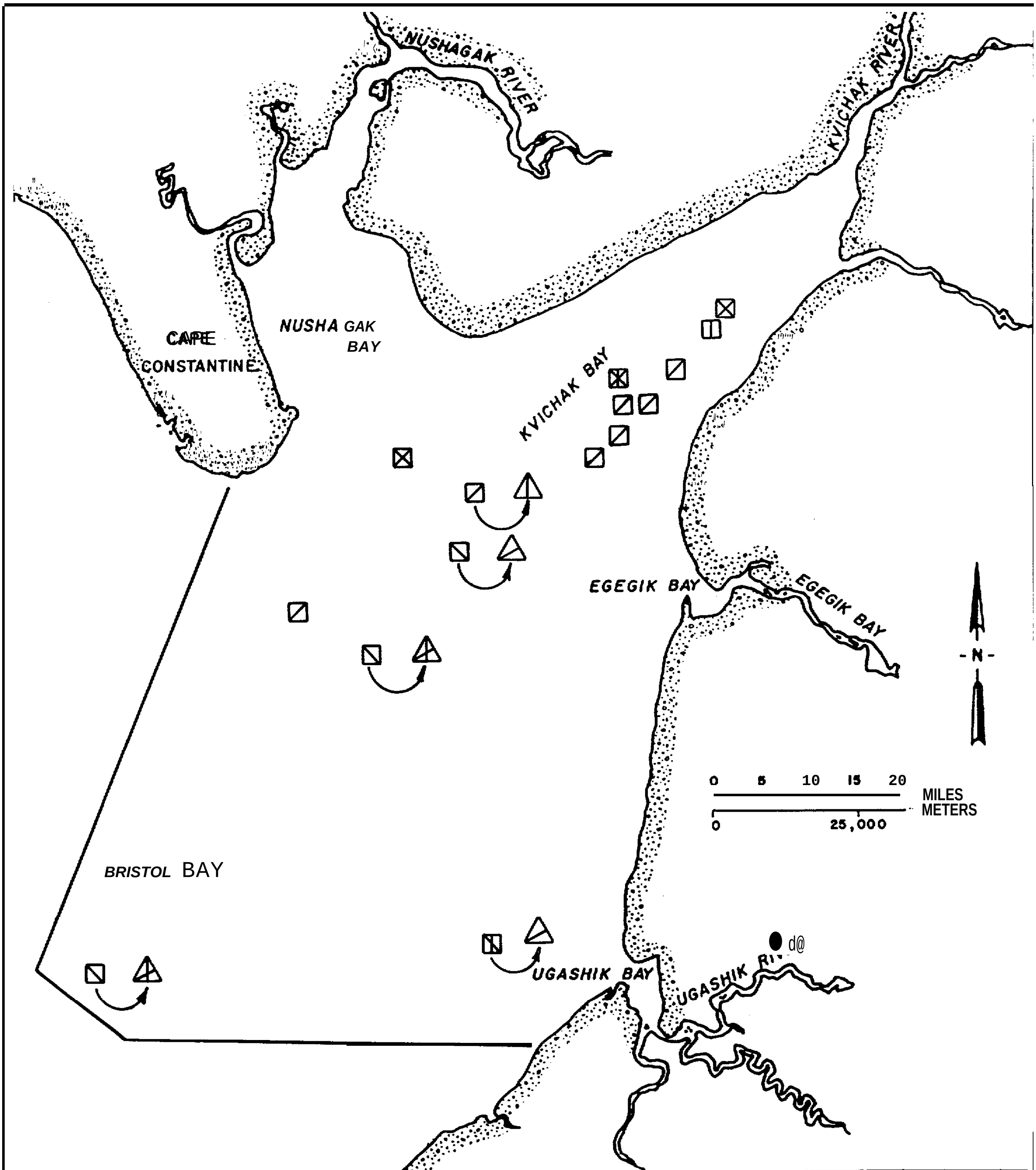
= CRUISE 83-5

BRISTOL BAY
RED KING CRAB

ROCK DREDGE SAMPLING STATIONS
BY CRUISE

FEBRUARY 1984

FIGURE 3.6-2



△ = CRUISE 83-3 } TRYNET
△ = CRUISE 83-5

□ = CRUISE 83-1 } ROCK DREDGE
□ = CRUISE 83-3
□ = CRUISE 83-5

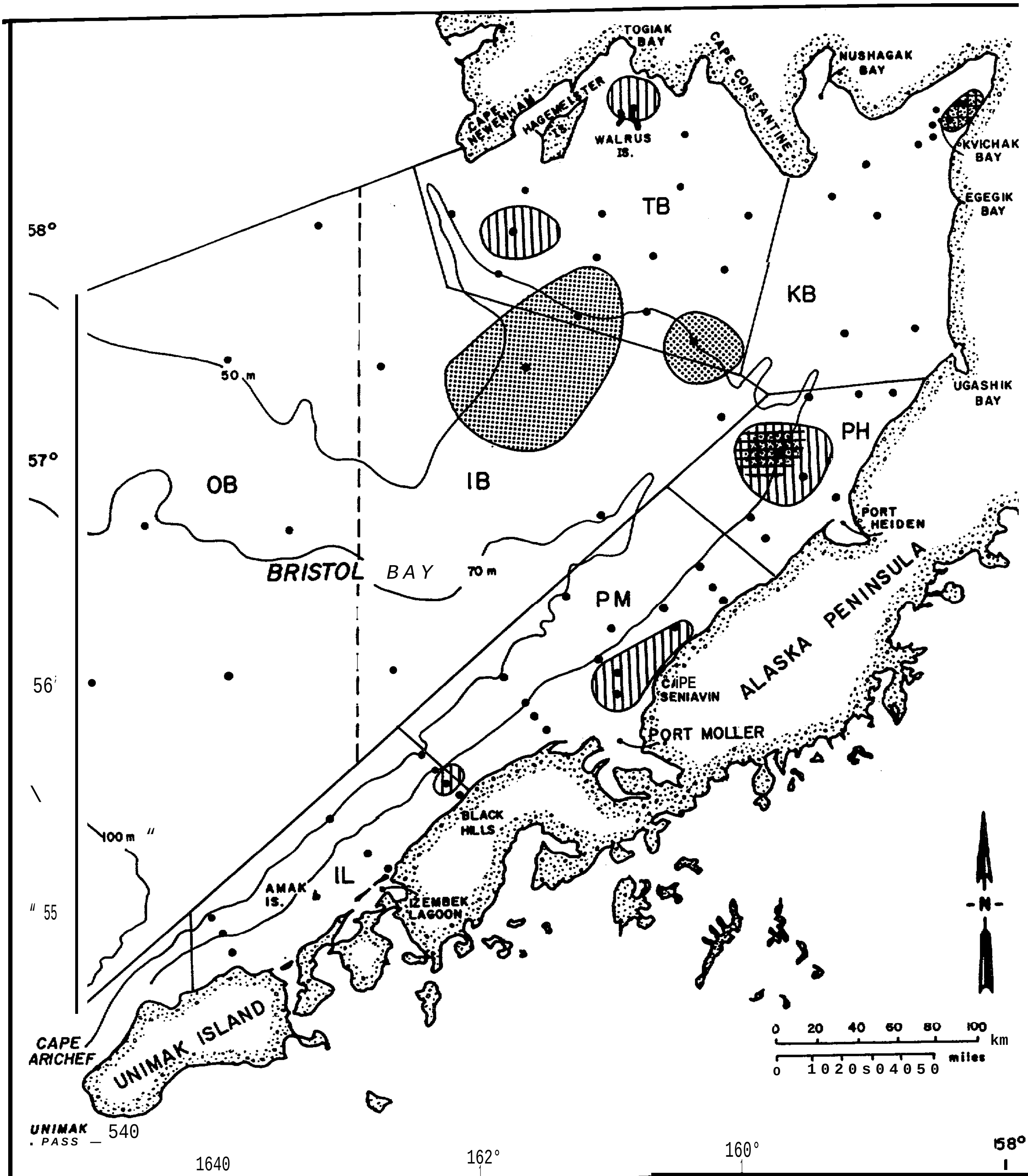
BRISTOL BAY
RED KING CRAB

TRY NET AND ROCK DREDGE SAMPLING STATIONS IN KVICHAK BAY BY CRUISE

FEBRUARY 1984 | FIGURE 3.6-3

A total of 317 crabs age 3 and younger was collected during the study. The distribution of these crabs, divided into apparent age groups, is shown by cruise in Figures 3.5-4, 3.5-5 and 3.5-6. All of the crabs in this size range were collected at 50 m or shallower depths, primarily in the four easternmost subareas: Port Moller (PM), Port Heiden (PH), Kvichak Bay (KB) and Togiak Bay (TB). The numbers of crabs collected per cruise from each of these subareas are summarized in Table 3.5-2. The KB and PH subareas yielded the greatest total numbers of small crabs, partially due to the greater number of samples taken in these areas (Table 3.5-l). Catch per station data, calculated as the sum of the mean catches per station divided by the number of stations sampled per subarea, are also presented in Table 3.5-2. Crab densities in the KB and PH subareas were generally higher than in other subareas during each cruise, with the exception of the TB area during April-May. The high value for the PH subarea during cruise 83-5 is primarily the result of a single catch of small crabs (59) at station PH230, using the trynet. The high value for the KB subarea during the same cruise is the result of six rock dredge hauls in the vicinity of station KB2*4 that each contained from seven to 37 small crabs, and a single trynet haul at station KB250 that contained 13 small crabs. The large catch at station PH230 consisted of almost equal numbers of YOY individuals and one year-old (1+) individuals, whereas the majority of crabs from the KB stations were young-of-the-year (Section 3.4).

The relative abundance of the age groups of juvenile crabs over the length of the study is presented in Figure 3.5-7. The catch per station data represent the mean number of crabs per station divided by the number of stations sampled in the entire study area for each of the three cruises. The greatest changes were the increase in numbers of young-of-the-year, 1 and 1+ crabs and the decrease in numbers of age 3 crabs. Age 2 and 2+ crabs were caught in very small numbers during April-May and June only.



AGE GROUPS

0+
1
1+

2
2+

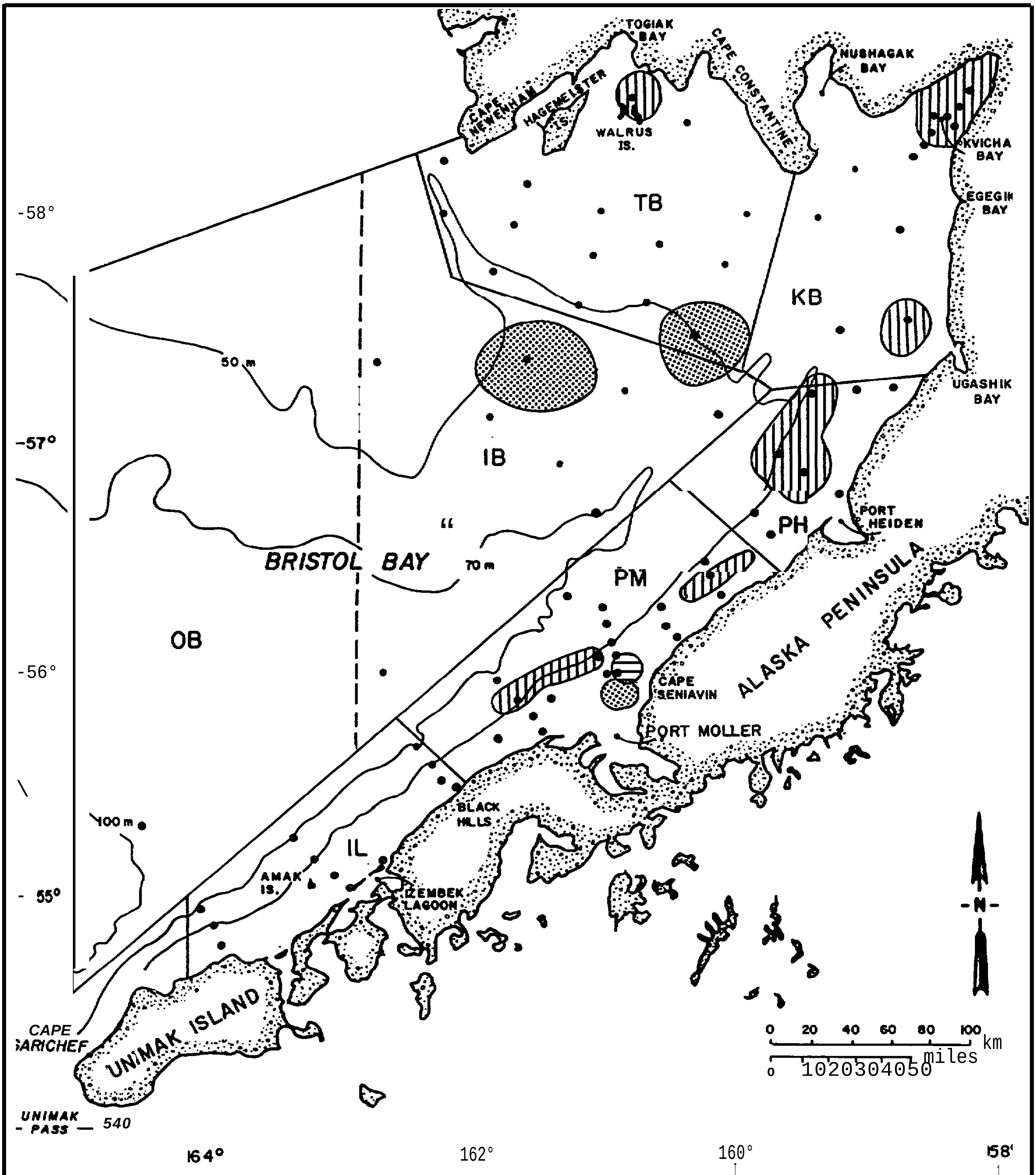
3 =

358

BRISTOL BAY
RED KING CRAB

DISTRIBUTION OF RED KING CRAB
AGE 3 AND YOUNGER **DURING**
CRUISE 83-1

FEBRUARY 1984 | FIGURE 3.6-4



AGE GROUPS

o+
I
l+

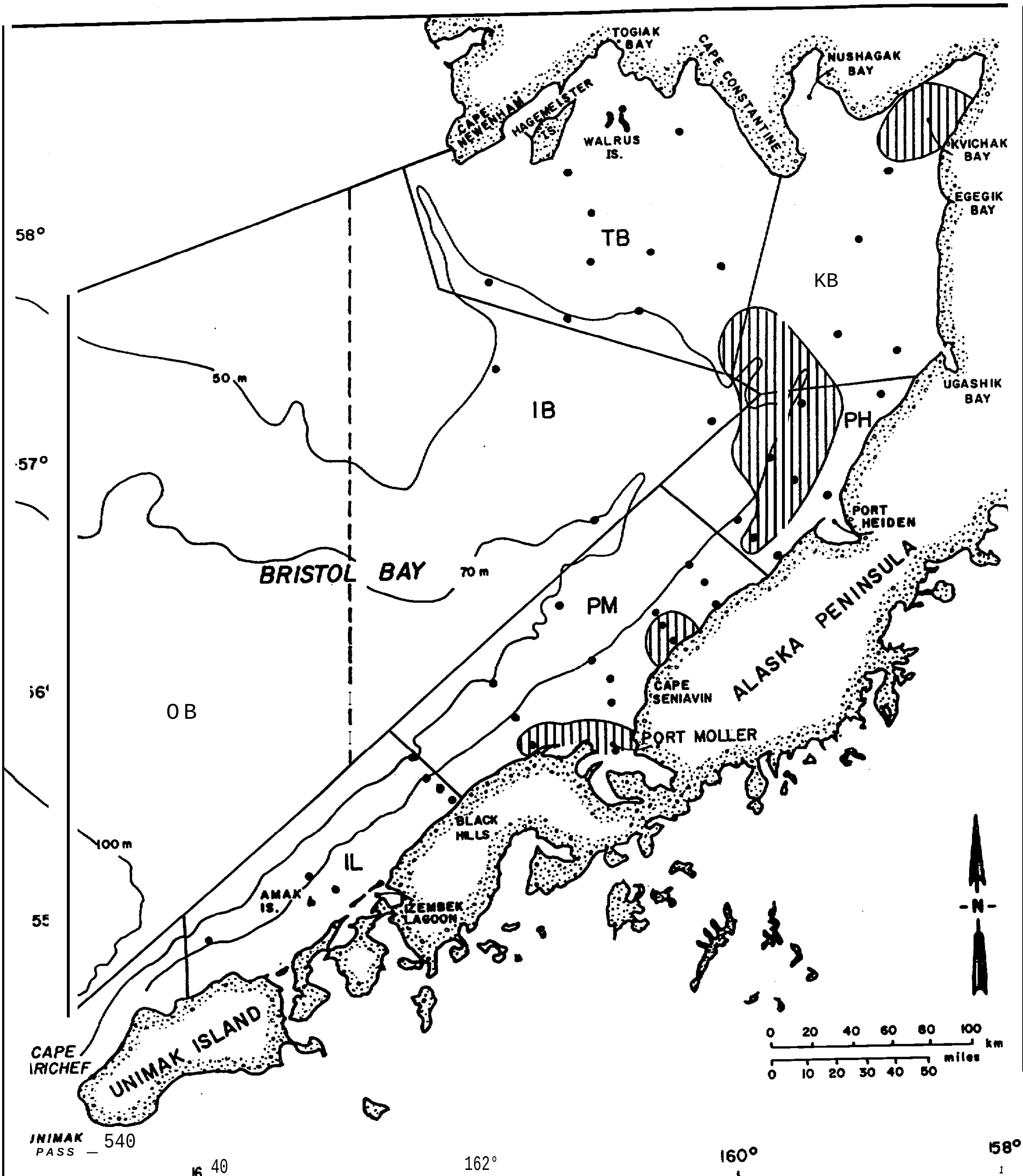
2
2+

3 =

BRISTOL BAY
RED KING CRAB

DISTRIBUTION OF RED KING CRAE
AGE 3 ANO YOUNGER **DURING**
CRUISE 83-3

FEBRUARY 1984 | FIGURE 3.6-5



AGE GROUPS

YOY
I
I+

2
2+

3

360

BRISTOL BAY
RED KING CRAB

DISTRIBUTION OF RED KING CRAB AGE 3 AND YOUNGER DURING CRUISE 836

FEBRUARY 1984

FIGURE 3.66

TABLE 3.5-2

TOTAL NUMBERS OF RED KING CRAB AGE 3 AND YOUNGER COLLECTED BY SAMPLING SUBAREAS

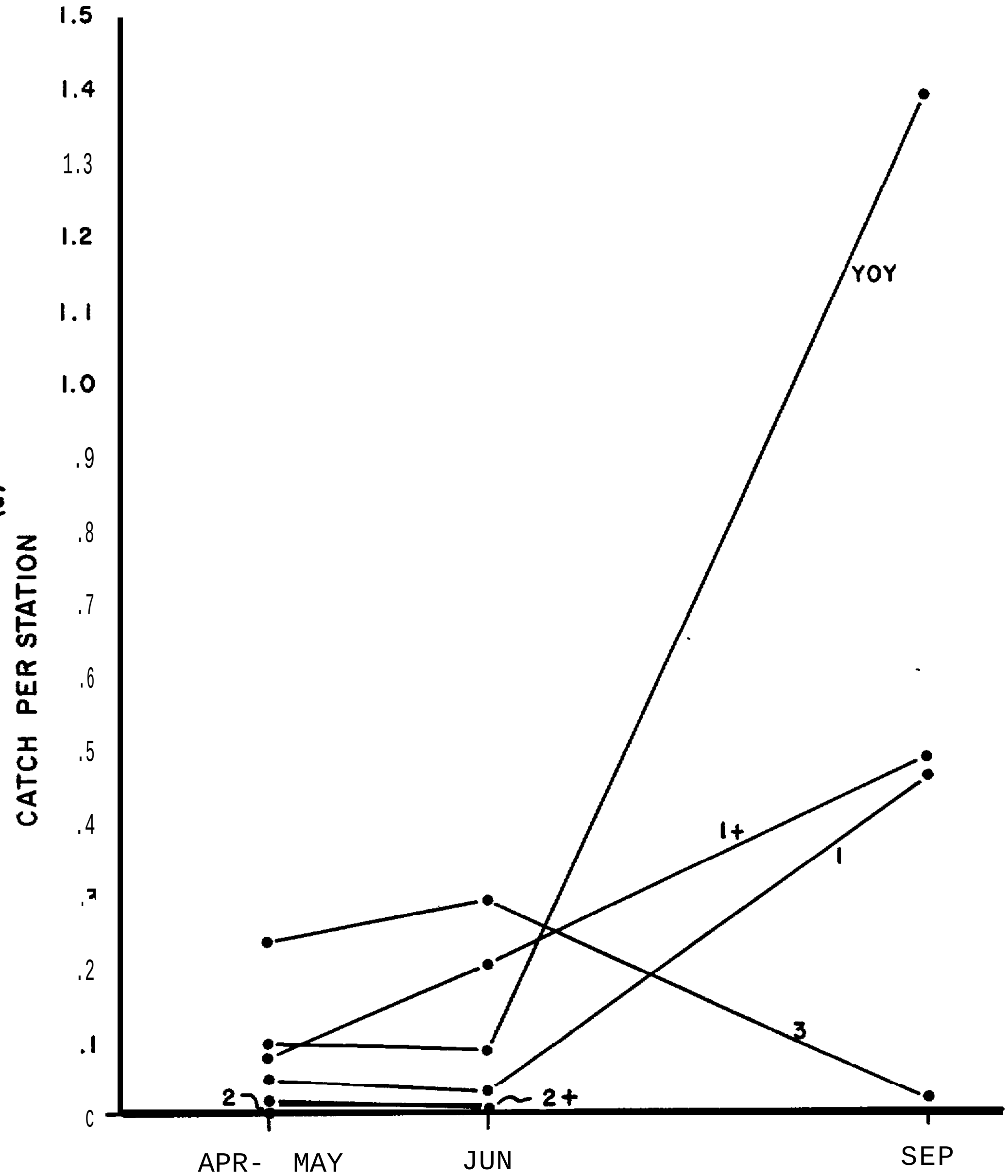
A. Total Numbers

Cruise	Sampling Subarea						Total
	BB	IL	PM	PH	KB	TB	
83-1:Apr-May	3	1	8	6	27	19	64
83-3:June	7	1	9	16	24	11	68
83-5:Sept	0	0	18	69	95	0	182
Total	10	2	35	91	146	30	314
%	3.2	0.6	11.2	29.0	46.5	9.6	

B. Catch Per Station(a)

Cruise	Sampling Subarea					
	BB	IL	PM	PH	KB	TB
83-1:Apr-May	0.2	0.1	0.3	0.6	0.8	1.0
83-3:June	0.7	0.1	0.3	1.0	1.4	0.6
83-5:Sept	0	0	1.1	8.6	4.4	0

(a) Catch per station = Mean number of crabs per station divided by number of stations sampled



AGE GROUPS:
YOY = YOUNG OF THE YEAR AND 0+
I-3 = AGE IN YEARS

(a)′ SUM OF MEAN NUMBER OF INDIVIDUALS PER STATION DIVIDED BY THE TOTAL NUMBER OF STATION SAMPLED.

NORTH ALEUTIAN BASIN

RED KING CRAB

AVERAGE CATCH PER STATION OF RED KING CRAB AGE 3 AND YOUNGER

FEBRUARY 1984 | FIGURE 3.5-7

The results of correlation analysis indicated that several physical and biological factors were related to the density distribution of red king crabs. Tables 3.5-3, 3.5-4 and 3.5-5 present the correlation matrices for cruises 83-1, 83-3 and 83-5, respectively. Generally, king crab density for age groups young-of-the-year through age 2 was negatively correlated with depth, whereas the density of crabs age 2+ and older was positively correlated with depth. Young-of-the-year crab density was positively correlated with gravel presence in sediments and with bottom water temperature. None of these correlations was statistically significant.

Variables related to the density distribution of 0+ or young-of-the-year crabs were bryozoan biomass during the April-May cruise (r=0.5280), sea urchin biomass during the June and September cruises (r=0.7011; r=0.5746, respectively), and polychaetes and gravel during the September cruise (r=0.8607, r=0.6090, respectively). Densities of age 1, 1+ and 2 crabs were significantly correlated with sea urchins (r=0.7239) during the April-May cruise, and with polychaetes and salinity (r=0.5225, r=0.6404, respectively), during the September cruise. Densities of crabs age 2+ and 3 were correlated with the sea onion (r=0.6965) during the April-May cruise, and with age 3+ and older red king crabs (r=0.5975) during the June cruise.

The results of multiple linear regression analysis are presented in Appendix E. For age class 0+, the sea star (*Asterias amurensis*) biomass was the most important variable for data from the April-May cruise, while sea urchin (*Strongylocentrotus droehbachiensis*) biomass was the most important variable in June. During September, three variables each accounted for 74 percent or more of the variability in YOY crabs for the single variable model; these were: polychaete biomass (r^2=0.7418); salinity (r^2=0.8211); and sea urchin biomass (r^2=0.9982).

Sea urchin biomass was also important in the regression models using data for age 1 through 2 crabs, accounting for 95 percent of the vari-

TABLE 3.5-3

CORRELATION MATRIX FOR RED KING CRAB ABUNDANCE AND ENVIRONMENTAL FACTORS DURING CRUISE 83-1 (APRIL-MAY)[a]

	Red King Crab Age				Biological Factors										Physical Factors			
	0+	1-2	2+&3	3++	Bryozoa	Flatfish	Other	Roundfish	Sea onion	Sea star	Sea urchin	Shrimps	Sponge	Polychaetes	Depth	Gravel	Temperature	Salinity
0+	1.000	-0.006	0.015	-0.021	0.528	0.012	0.200	-0.006	-0.068	0.451	-0.021	0.187	0.056	-0.028	-0.149	0.088	0.047	0.009
1-2		1.000	0.271	0.380	-0.021	-0.079	0.284	-0.056	-0.053	-0.032	0.975	0.001	0.469	-0.009	-0.191	0.483	0.073	-0.427
2+ and 3			1.000	0.408	-0.026	-0.066	0.073	-0.053	0.696	0.700	0.267	0.002	0.412	-0.022	0.006	0.036	-0.124	-0.276
3++				1.000	-0.050	-0.061	0.089	0.010	0.416	0.274	0.374	-0.031	0.484	-0.045	0.047	0.063	-0.249	-0.138
Bryozoa					1.000	0.033	0.025	-0.025	-0.044	0.325	-0.021	0.066	0.094	-0.017	-0.083	-0.022	0.019	0.056
Flatfish						1.000	-0.128	0.114	0.016	-0.035	-0.087	0.067	-0.026	0.028	-0.085	-0.224	-0.095	0.079
Other							1.000	-0.034	-0.014	0.045	0.277	-0.074	0.183	-0.025	0.036	0.138	0.118	-0.260
Roundfish								1.000	-0.091	-0.101	-0.059	-0.045	-0.082	0.063	0.302	-0.150	0.191	0.252
Sea onion(b)									1.000	-0.567	-0.055	-0.036	0.438	-0.045	0.182	-0.177	-0.179	0.323
Sea star(c)										1.000	-0.049	0.126	0.260	-0.023	-0.066	-0.139	-0.134	-0.027
Sea urchin(d)											1.000	0.098	0.461	-0.009	-0,200	0.523	0.060	-0.550
Shrimps												1.000	-0.056	0.087	-0.355	0.201	0.181	-0.580
Sponge													1.000	-0.042	-0.004	0.171	-0.121	-0.134
Polychaetes(e)														1.000	-0.080	0.019	-0.012	-0.071
Oepth															1.000	-0.530	-0.015	0.560
Gravel																1.000	0.241	-0.657
Temperature																	1.000	-0.018
Salinity																		1.000

(a) 0.555 = significant at $p<0.01$
(b) *Boltenia ovifera*
(c) *Asterias amurensis*
(d) *Strongylocentrotus droehbachiensis*
(e) Tube-building polychaetes only

TABLE 3.5-4

CORRELATION MATRIX FOR RED KING CRAB ABUNDANCE AND ENVIRONMENTAL FACTORS DURING CRUISE 83-3 (JUNE)(a)

	Red King Crab Age				Biological Factors										Physical Factors			
	O+	1-2	2+ & 3	3++	Bryozoa	Flatfish	Other	Roundfish	Sea onion	Sea star	Sea urchin	Shrimps	Sponge	Polychaetes	Depth	Gravel	Temperature	Salinity
O+	1.000	-0.016	0.061	-0.077	0.256	-0.164	0.108	0.115	-0.072	0.074	0.701	0.032	0.004	-0.031	-0.113	0.079	0.014	0.084
1-2		1.000	0.050	-0.051	-0.053	-0.090	-0.031	-0.054	-0.049	-0.044	-0.030	-0.029	0.004	-0.021	-0.144	-0.071	-0.018	-0.015
2+ and 3			1.000	0.597	-0.065	-0.024	0.463	0.130	0.112	0.303	-0.049	-0.037	0.264	-0.033	0.099	-0.117	-0.138	0.157
3++				1.000	-0.051	0.024	0.125	0.069	0.588	-0.067	-0.065	-0.058	0.311	-0.045	0.249	-0.106	-0.110	-0.222
Bryozoa					1.000	-0.125	0.050	0.009	-0.025	0.056	0.102	0.046	0.071	-0.044	-0.034	-0.061	0.053	0.087
Flatfish						1.000	-0.186	0.155	-0.070	-0.009	-0.071	0.018	-0.050	-0.126	-0.332	-0.007	-0.430	-0.382
Other							1.000	0.325	0.190	0.100	-0.008	0.159	0.320	-0.069	0.078	-0.071	-0.236	0.212
Roundfish								1.000	-0.143	0.096	0.035	0.482	-0.037	-0.070	-0.221	0.459	-0.040	-0.017
Sea onion(b)									1.000	-0.198	0.055	-0.053	0.389	-0.036	0.366	-0.110	-0.080	0.220
Sea star(c)										1.000	-0.015	-0.114	-0.015	-0.017	-0.187	-0.058	-0.105	0.088
Sea urchin(d)											1.000	-0.034	0.169	-0.025	-0.134	-0.048	0.029	0.070
Shrimps												1.000	-0.052	-0.025	-0.131	0.463	0.112	-0.157
Sponge													1.000	-0.037	0.243	-0.149	-0.071	-0.190
Polychaetes(e)														1.000	0.124	-0.073	-0.115	0.073
Depth															1.000	-0.401	-0.329	0.500
Gravel																1.000	0.203	-0.258
Temperature																	1.000	-0.756
Salinity																		1.000

(a) 0.555 = Significant at $p<0.01$
(b) *Boltenia ovifera*
(c) *Asterias amurensis*
(d) *Strongylocentrotus droehbachiensis*
(e) Tube-building polychaetes only

TABLE 3.5-5

CORRELATION MATRIX FOR REO KING CRAB ABUNOANCE AND ENVIRONMENTAL FACTORS DURING CRUISE 83-5 (SEPTEMBER)

	Red King Crab Age				Biological Factors										Physical Factors			
	YOY	1-2	2+ & 3	3++	Bryozoa	Flatfish	Other	Roundfish	Sea onion	Sea star	Sea urchin	Shrimps	Sponge	Polychaetes	Depth	Gravel	Temperature	Salinity
YOY	1.000	0.224	0.000	-0.043	-0.060	-0.076	0.059	-0.022	-0.055	-0.030	0.575	0.032	0.197	0.861	-0.196	0.609	0.199	-0.483
1-2		1.000	0.000	-0.085	-0.188	-0.107	-0.046	-0.084	-0.080	-0.078	0.385	0.020	-0.019	0.522	-0.339	0.210	0.248	-0.640
2+ and 3			0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3++				1.000	0.052	0.020	0.062	-0.174	0.539	-0.159	-0.058	-0.111	0.022	-0.055	0.432	-0.152	-0.506	0.124
Bryozoa					1.000	-0.090	-0.032	-0.012	0.042	0.081	0.441	0.074	-0.057	-0.081	-0.297	-0.031	0.030	-00061
Flatfish						1.000	-0.074	0.612	-0.024	0.430	0.099	0.001	-0.115	-0.095	-0.077	-0.162	0.053	0.120
Other							1.000	-0.120	0.010	-0.140	0.014	-0.078	-0.006	-0.005	-0.020	0.081	0.096	0.019
Roundfish								1.000	-0.175	0.318	0.024	0.179	-0.178	-0.039	-0.160	-0.022	0.106	0.063
Sea onion(b)									1.000	-0.147	0.001	-0.090	0.002	-0.073	0.476	-0.132	-0.249	-0.137
Sea star(c)										1.000	0.113	0.061	-0.118	0.006	-0.059	-0.221	-0.029	0.050
Sea urchin(d)											1.000	0.116	0.091	0.489	-0.304	0.624	0.192	-0.485
Shrimps												1.000	-0.093	0.003	-0.198	0.465	0.097	-0.146
Sponge													1.000	0.153	-0.140	0.528	0.017	-0.036
Polychaetes(e)														1.000	-0.197	0.504	0.222	-0.401
Depth															1.000	-0.493	-0.442	0.429
Gravel																1.000	0.218	-0.633
Temperature																	1.000	-0.327
Salinity																		1.000

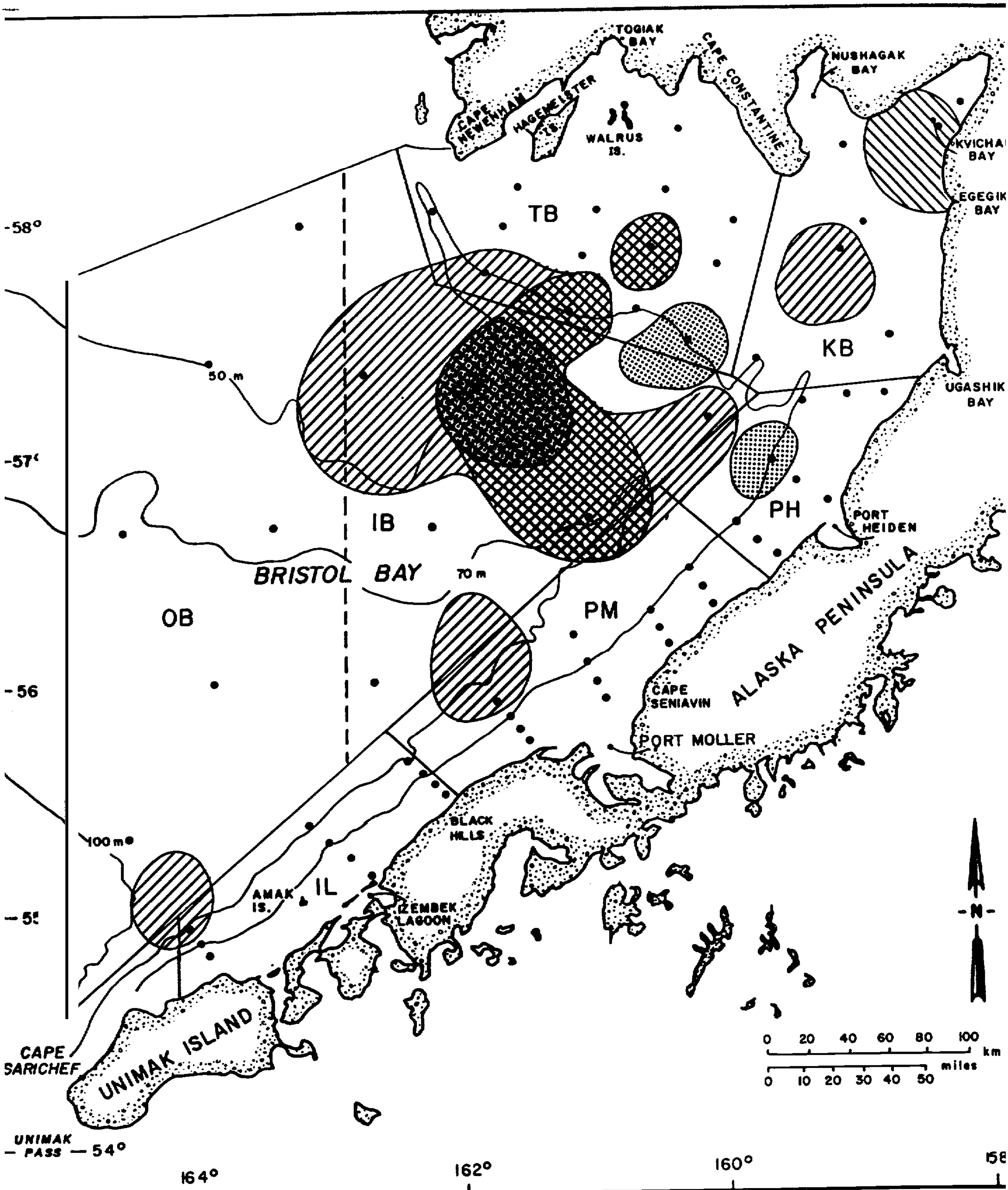
(a) 0.555 = Significant at $p<0.01$
(b) *Boltenia ovifera*
(c) *Asterias amurensis*
(d) *Strongylocentrotus droehbachiensis*
(e) Tube-building polychaetes only

ability (r^2=0.9530) in the single variable model for the April-May cruise data. Using the September data, the combination of polychaete and sea urchin biomass in the two-variable model accounted for 92 percent of the variability (i.e., r^2=0.9239). The sea urchin was again an important variable in the analysis of data for age 2+ and 3 crabs during April-May, accounting for 57 percent of the variability (r^2=0-.5699) in the single variable mode l.

3.6 Adult Distribution Patterns

The distribution of red king crab >68 mm carapace length is shown in Figures 3.6-1, 3.6-2 and 3.6-3 for cruises 83-1, 83-3 and 83-5, respectively. These larger crabs were found primarily at depths >50 m in the TB and IB subareas. The total numbers of larger crabs collected and the calculated catch per station are presented in Table 3.6-1, which shows that relatively few large crabs were collected during this study. The greatest numbers of crabs were taken from BB and TB stations; the 15 individuals from the IL subarea during cruise 83-1 were taken in a single trynet haul. Most large crabs captured were taken with the trynet, although a few were collected in rock dredge hauls from the KB and TB subareas.

The decrease in the catch of large crabs during the September cruise (83-5) resul ted partial 1 y from a decreased sampling effort, especial 1 y in the BB subarea, as indicated by the station locations in Figure 3.6-3. This decline also reflects an assumed shift in the distribution of these crabs. Although the majority of large crabs were found in the inner BB and TB subareas, some were found in the IL, PM, PH and KB subareas during April-Nay and June (Figures 3.6-1 and 3.6-2, respectively). Also, while the majority of crabs were found at depths between 50 and 70 m, some were found at shallower depths during the first two cruises, such as stations KB2*4 and KB2*9 (both 14 m depth) and TB330 (30 m depth). During the September cruise (83-5), a few crabs were found along the edge of the PM subarea and inner BB at 70 m depth, and



AGE:

3+ = (stippled)

4 = (hatched)

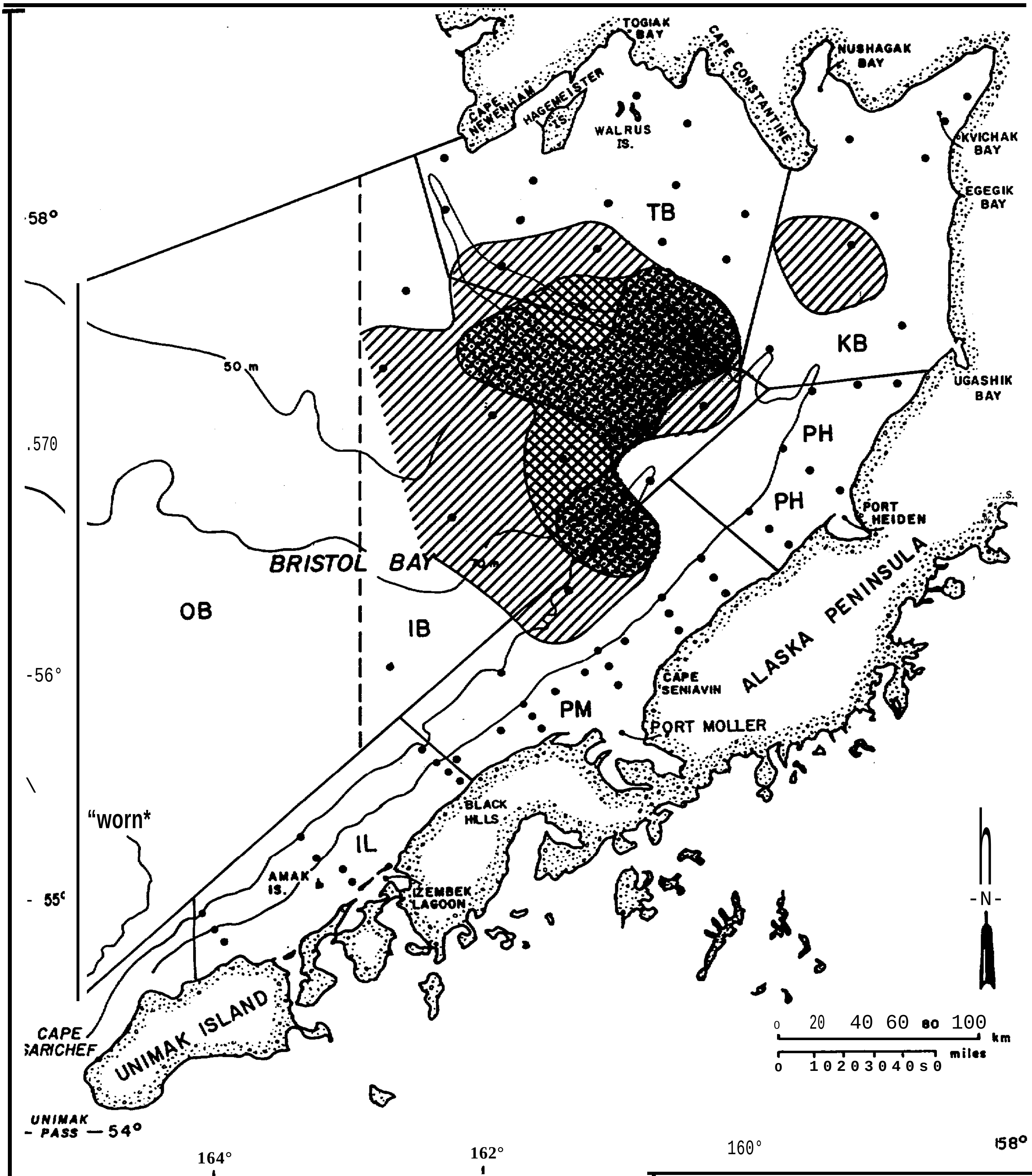
4 + = (hatched)

• = SAMPLING STATION

BRISTOL BAY
RED KING CRAB

DISTRIBUTION OF RED KING CRAI
OLDER THAN 3 YEARS
DURING CRUISE S3-1

FEBRUARY 1984 **FIGURE** 3.61



AGE:

3+ =

4 =

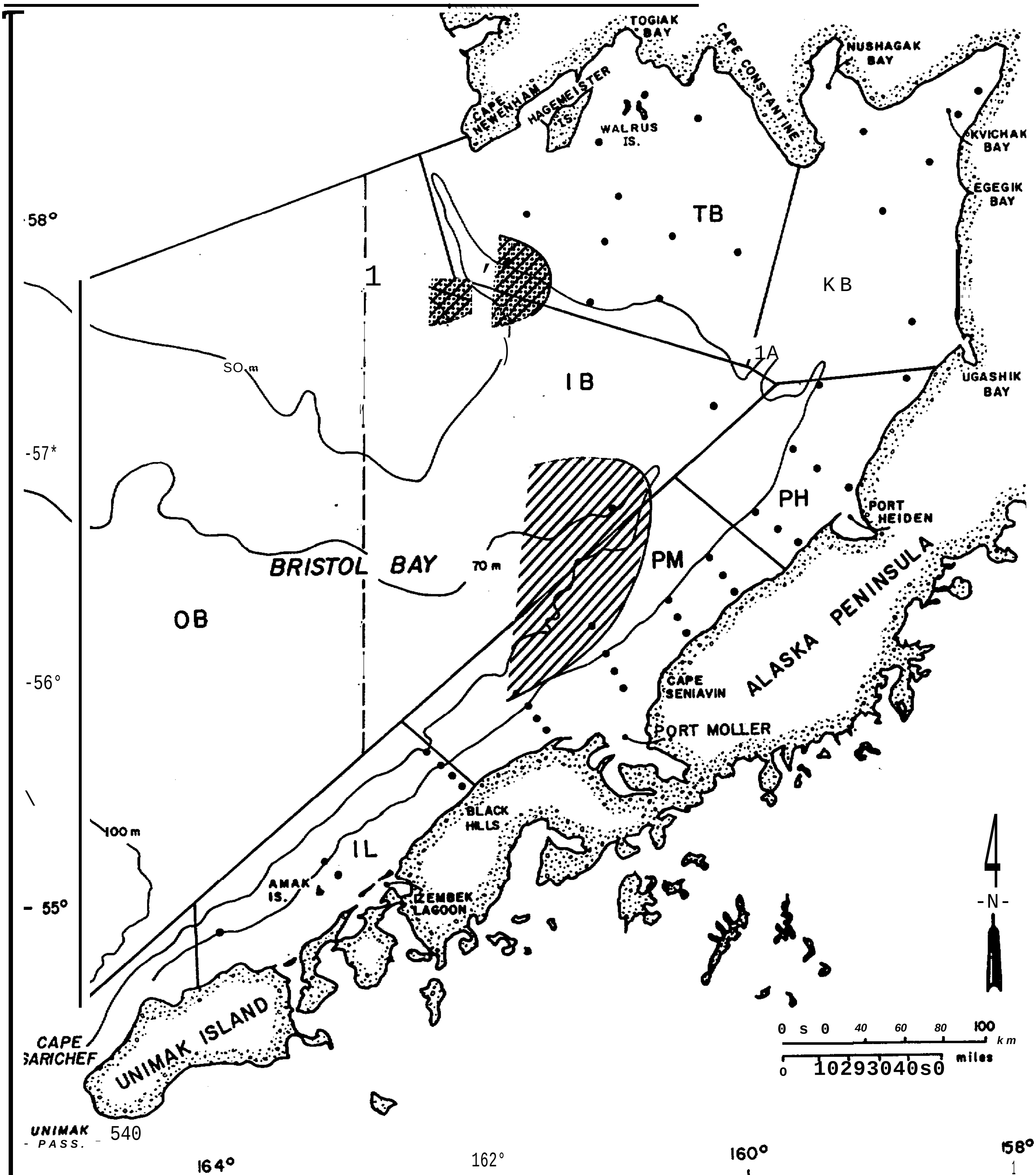
4+ =

• = SAMPLING STATION

BRISTOL BAY
RED KING CRAB

DISTRIBUTION OF RED KING CRAB
OLDER THAN 3 YEARS
DURING CRUISE 83-3

FEBRUARY 1984 | FIGURE 3.8-2



AGE:

3 + =

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• SAMPLING STATION

BRISTOL BAY
RED **KING** CRAB

DISTRIBUTION OF RED KING CRAB
OLDER **THEN 3** YEARS
DURING CRUISE **83-5**

FEBRUARY 1084 | FIGURE 3.6-3

TABLE 3.6-1

TOTAL NUMBERS AND CATCH PER STATION OF RED KING CRAB >60 MM LENGTH

A. Total Numbers

Cruise	Sampling Area						Total
	BB	IL	PM	PH	KB	TB	
83-1:Apr-May	11	15	2	0	3	9	40
83-3:June	11	0	3	0	1	9	24
83-5:Sept	2	0	2	0	0	1	5
Total	24	14	7	0	4	19	69

B. Catch Per Station(a)

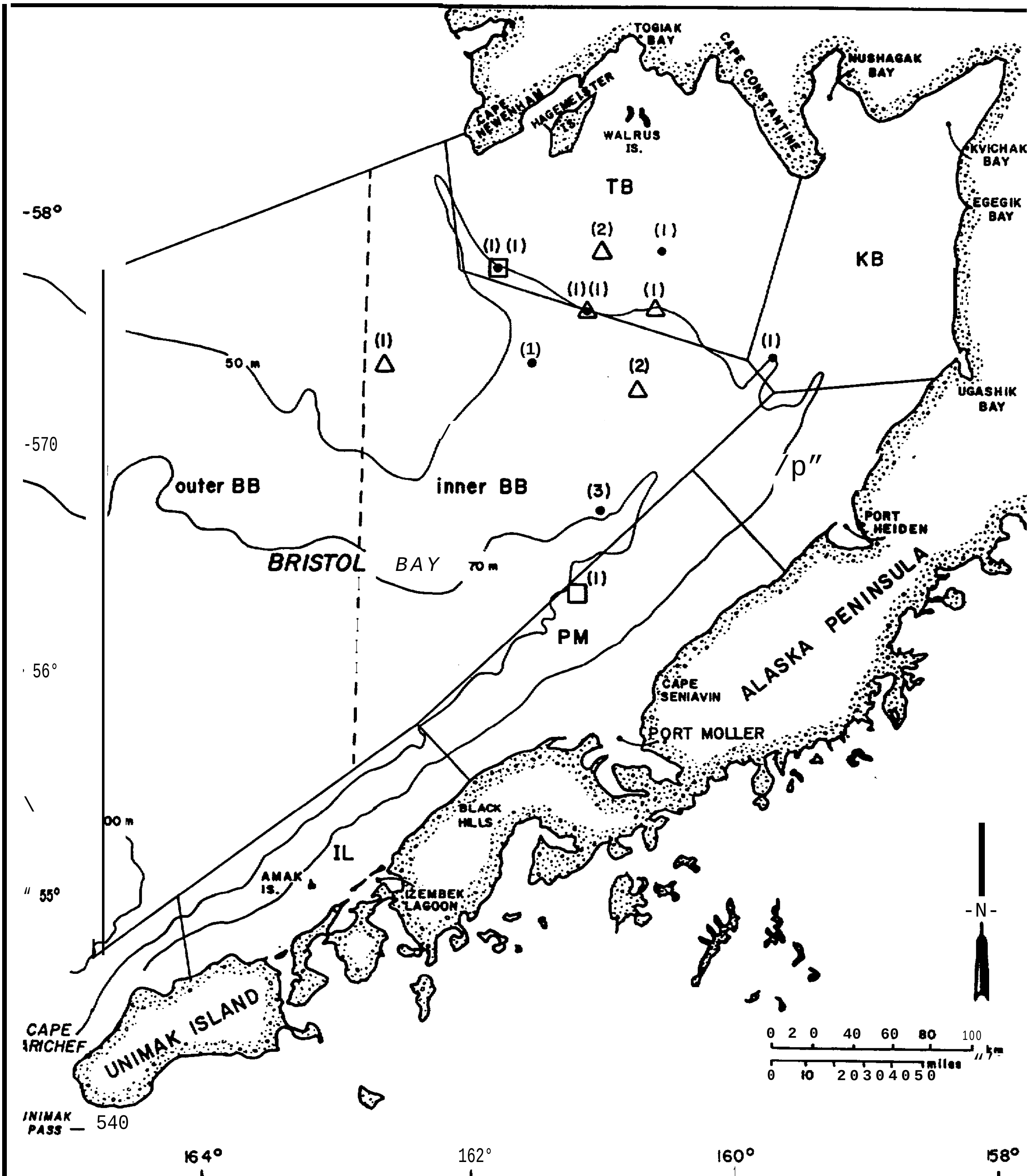
Cruise	Sampling Area					
	BB	IL	PM	PH	KB	TB
83-1:Apr-May	2.7	1.5	0.1	0.3	0.2	1.5
83-3:June	4.1	0	0.1	0.7	<.1	2.1
83-5:Sept	1.0	0	0.1	0	0	0.2

(a) Catch per station = Mean number of crabs per station divided by number of stations sampled at one 50 m deep TB station west of the TB stations where crabs had been previously found (Figure 3.6-3).

Results of correlation analysis using densities of age 3+ and older red king crabs (Tables 3.5-3 to 3.5-5) indicated a positive, although not significant, correlation with depth and a general negative correlation with bottom water temperature. Densities of these crabs correlated with sea onion biomass during the June and September cruises ($r=0.5877$, $r=0.5391$, respectively). Bottom water temperature showed a strong negative correlation during September ($r=0.5056$).

Multiple linear regression results are shown in Appendix E. Sea urchin biomass was the most important single variable ($r^2=0.4224$) during April-May, with the greatest variability explained in the five-variable model by the combination of sea urchin, flatfishes, round-fishes, salinity and temperature ($r^2=0.6149$). Analyses of data from the September cruise resulted in the sea onion being most important in the single variable model ($r^2=0.3873$); sea onion and temperature were most important in the two-variable model ($r^2=0.5714$); and the combination of sea onion, temperature, bryozoa, flatfishes and round-fishes accounted for the greatest variability in the five-variable model ($r^2=0.6212$).

A small number of ovigerous female red king crabs were collected during this study; their distribution is shown in Figure 3.6-4. Most of the ovigerous females found were in the vicinity of the 50 m isobath separating the TB and BB subareas. Three individuals were found at 70 m in the eastern part of subarea BB during the April-May cruise, and one individual was found at 70 m along the PM-BB border during the September cruise. The biological information collected for ovigerous females is summarized in Table 3.6-2. Egg condition information shown in the table indicates that larvae were hatching as late as the June cruise in some areas.



● = CRUISE 83-1

△ = CRUISE 83-3

□ = CRUISE 83-5

(N) = NUMBER OF OVIGEROUS CRABS COLLECTED

373

BRISTOL BAY
RED KING CRAB

DISTRIBUTION OF OVIGEROUS FEMALE RED KING CRAB

FEBRUARY 1984

FIGURE 3.6-4

TABLE 3.6-2

SUMMARY OF BIOLOGICAL INFORMATION COLLECTED
FOR OVIGEROUS FEMALE RED KING CRAB

Cruise	Station	Carapace Length (mm)	SC[a]	Color[b]	Condition[c]	Clutch Size[d]	Wet Weight (g)
83-1	BB770	90	1	2	1		
		92	1	2	1		
		120	3		2		
	KB250	85	3		2		523
	TB431	89	1	2	1		
	TB350	88	2	3	1		
	BB557	83	2		2		
	TB250	90	3		2		
83-3	TB330	111	2	2	1	7	862
		96	2	2	1	6	636
	TB450	118	4	3	2	4	1,331
	TB350	97	2	3	1		665
	BB450	120	2	2	1	3	918
	BB665	92		5	1		632
		93		5	1		586
83-5	TB250	105	1	3	1	6	707
	PM670	96	1	3	1	6	739

(a) SC = Shell condition: 1 = Hard shell with sharp vertical spines
2 = Clean shell, ventral spines dull
3 = Old shell, small amount of growth
4 = Very old shell, lots of growth, scars, dirty

(b) Egg color: 2 = Purple
3 = Brown
5 = Purple/brown

(c) Egg condition: 1 = Pie-eyed
2 = Eyed

(d) Clutch size: 3 = 1/4 full
4 = 1/2 full
6 = full
7 = bulging

3.7 Epibenthic Associations

A variety of fish and invertebrate species was collected and enumerated in trynet and rock dredge samples. A general picture of distributional patterns of species groups, or associations, can be derived from the collection data. Trynet samples provided a more reliable quantitative data set due to the efficiency of the sampling gear on the bottom types sampled. The rock dredge data were much less reliable, and many rock dredge hauls were treated qualitatively.

Trynet biomass data, expressed as mean catch per unit effort (CPUE, g m^{-2}), were used to assess the relative importance of major taxonomic groups (Table 3.7-1). Trynet samples were dominated by pleuronectids, asteroids and ascidians. The pleuronectids were represented primarily by yellowfin sole (Limanda aspera) and rock sole (Lepidopsetta bilineata), the asteroids were primarily Asterias amurensis, and the ascidians were almost all Boltenia ovifera. Pleuronectids ranged from 41 to 51 percent, asteroids from 18 to 33 percent, and ascidians from 3.3 to 7.7 percent of the total mean CPUE per cruise. These three groups combined ranged from 72.7 to 85.3 percent of the total mean CPUE per cruise.

Fish taxa of secondary importance in trynet samples included the codfishes (Gadidae) and sculpins (Cottidae); these groups accounted for from 3 to 13 percent of fish mean CPUE (% catch) per cruise, and from 2 to 8 percent of the total mean CPUE (% total) per cruise. Invertebrate taxa of secondary importance included the sand dollar, Echinarachnius parma (Echinoidea), sponge (Porifera), red king crab (Paralithodes) and crangon shrimps (Crangonidae). Marine tube-building worms (Polychaeta) *were* important in the April-May samples.

The total mean CPUE for trynet samples increased from 5.6 g m^{-2} during the April-May cruise to 15.4 g m^{-2} during June and 17.40 g m^{-2} during September. These increases were largely a result of greater flatfish and sea star catches during the latter two cruises (Table 3.7-l).

TABLE 3.7-1

SUMMARY OF TRY NET CATCH PER UNIT EFFORT BY TAXONOMIC GROUP AND CRUISE DURING 1983

	Cruise 83-1 (April-May)			Cruise 83-3 (June)			Cruise 83-5 (September)		
	CPUE(a)	Percent Catch	Percent Total	CPUE	Percent Catch	Percent Total	CPUE	Percent Catch	Percent Total
Vertebrates									
Rajidae	0.0000	0.00	0.00	0.0243	0.28	0.16	0.0000	0.00	0.00
Pleuronectidae	2.7126	82.55	48.67	7.9384	90.36	51.60	7.1529	89.42	41.10
Agonidae	0.0079	0.24	0.14	0.0164	0.19	0.11	0.0330	0.41	0.19
Ammodytidae	0.0071	0.21	0.13	0.0148	0.17	0.10	0.0046	0.06	0.03
Cl upei dae	0.0001	0.00	0.00	0.0000	0.00	0.00	0.0000	0.00	0.00
Cottidae	0.1107	3.37	1.99	0.4243	4.83	2.76	0.3080	3.85	1.77
Trichodontidae	0.0001	0.00	0.00	0.0012	0.01	0.01	0.0017	0.02	0.01
Gadidae	0.4419	13.45	7.93	0.2898	3.30	1.88	0.4202	5.25	2.41
Hexagrammidae	0.0004	0.01	0.01	0.0110	0.13	0.07	0.0335	0.42	0.19
Cyclopteridae	0.0000	0.00	0.00	0.0013	0.01	0.01	0.0012	0.01	0.01
Osmeridae	0.0025	0.08	0.05	0.0374	0.43	0.24	0.004B	0.06	0.03
Stichaeidae	0.0018	0.06	0,03	0.0257	0.29	0.17	0.03B9	0.49	0.22
Phol idae	0.0001	0.00	0.00	0.0005	0.01	0.00	0.0006	0.01	0.00
Zoarcidae	0.0007	0.02	0.01	0.0000	0.00	0.00	0.0003	0.00	0.00
Total	3.2859	100.00	58.95	8.7851	100.00	57.10	7.9996	100.00	45.96
Invertebrates									
Anthozoa	0.0286	1.25	0.51	0.1067	1.62	0.69	0.2171	2.31	1.25
Pol ychaeta	0.1713	7.49	3.07	0.0000	0.00	0.00	0.0277	0.29	0.16
Cirripedia	0.0043	0.19	0.08	0.0454	0.69	0.30	0.0000	0.00	0.00
Pandal idae	0.0008	0.04	0.01	0.1675	2.54	1.09	0.0648	0.69	0.37
Hippolytidae	0.0000	0.00	0.00	0.0003	0.00	0.00	0.0002	0.00	0.00
Crangonidae	0.0559	2.45	1.00	0.1321	2.00	0.86	0.1550	1.65	0.89
Cancer	0.0000	0.00	0.00	0.0007	0.01	0.00	0.0036	0.04	0.02
Ma jidae	0.0591	2.58	1.06	0.0905	1,37	0.59	0.1007	1.07	0.58
Paguridae	0.0146	0.64	0.26	0.0187	0.28	0.12	0.0267	0.28	0.15
Paralithodes	0.2224	9.72	3.99	0.1839	2.79	1.20	0.0359	0.38	0.21
Erimacrus	0.0045	0.20	0.08	0.0004	0.01	0.00	0.0203	0.22	0.12
Gastropoda	0.0464	2.03	0.83	0.0561	0.85	0.36	0.0220	0.23	0.13
Pelecypoda	0.0120	0.52	0.21	0.0127	0.19	0.08	0.0197	0.21	0.11
Asteroidea	1.0196	44.57	18.29	3.9982	60.58	25.99	5.7531	61.17	33.05
Echinoidea	0.2086	9.12	3.74	0.1559	2.36	1.01	2.0420	21.71	11.73
Gorgonocephalid	0.0132	0.5B	0.24	0.0136	0.21	0.09	0.0279	0.30	0.16
Holothuroidea	0.0000	0.00	0.00	0.0323	0.49	0.21	0.1042	1.11	0.60
Pori fera	0.1090	4.76	1.96	0.3944	5.98	2.56	0.2031	2.16	1.17
Ascidiacea	0.3174	13.87	5.69	1.1897	18 .03	7.73	0.5813	6.18	3.34
Total	2.2877	100.00	41.05	6.5993	100.00	42.90	9.4053	100.00	54.04
GRAND TOTAL	5.5737		100.00	15.3845		100.0	17.4049		100.00

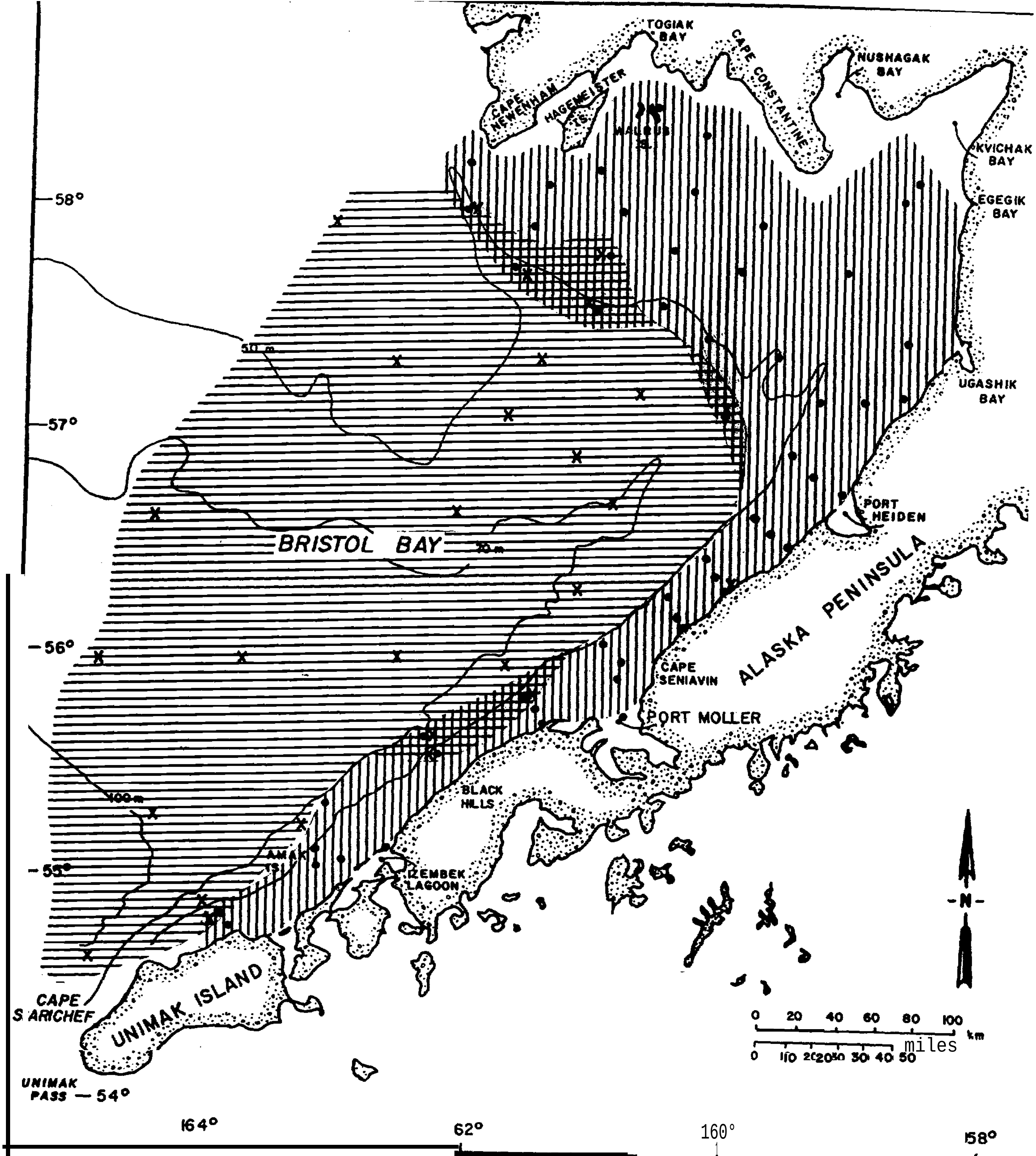
(a)CPUE. Catch per unit effort (g in⁻²)

Dendrograms and two-way tables (not illustrated) were generated by multivariate methods (EAP 1982). Similarity analysis of biomass data from trynet samples resulted in the identification of two major sample groups. The distribution of samples in these two groups is displayed in Figure 3.7-1. The two groups, an offshore and nearshore group, overlap between the 50 and 70 m isobaths along the Alaska Peninsula and along the 50 m isobath in the northeast portion of the study area. The average depth of the 43 samples in the offshore group was about 62 m; the 99 samples in the nearshore group averaged about 36 m depth.

Similarity analysis resulting in species groups exhibited a great degree of species overlap between sample groups, indicating widespread distributions for many of the species taken in trynet samples. A group of three species occurred at their maximum biomass in the offshore samples: the red king crab, the ascidian Boltenia ovifera ; and the Tanner crab (Chionoecetes bairdi). The king crabs in these offshore samples were primarily adults and older juveniles. The species characteristic of nearshore trynet samples included: yellowfin sole (Limanda aspera); rock sole (Lepidopsetta bilineata); sea star (Asterias amurensis); hermit crab (Pagurus ochotensis); Pacific cod (Gadus macrocephalus); and pollock (Theragra chalcogramma). These species were also present in offshore samples, but at lower biomass values.

Two major sample groups were also identified from similarity analysis of rock dredge biomass data; their distributions are shown in Figure 3.7-2. Samples in group AB had a more widespread distribution than those in group CD, which was found along shore and in shallow areas. The 33 group AB samples had an average depth of approximately 37 m; the 34 group CD samples averaged about 23 m depth.

The four species groups identified from the rock dredge data formed two major groups. The species characteristic of sample group AB were essentially those described for the trynet nearshore group. Rock dredge hauls in sample group CD were generally devoid of the major species of



= NEARSHORE ASSEMBLAGE

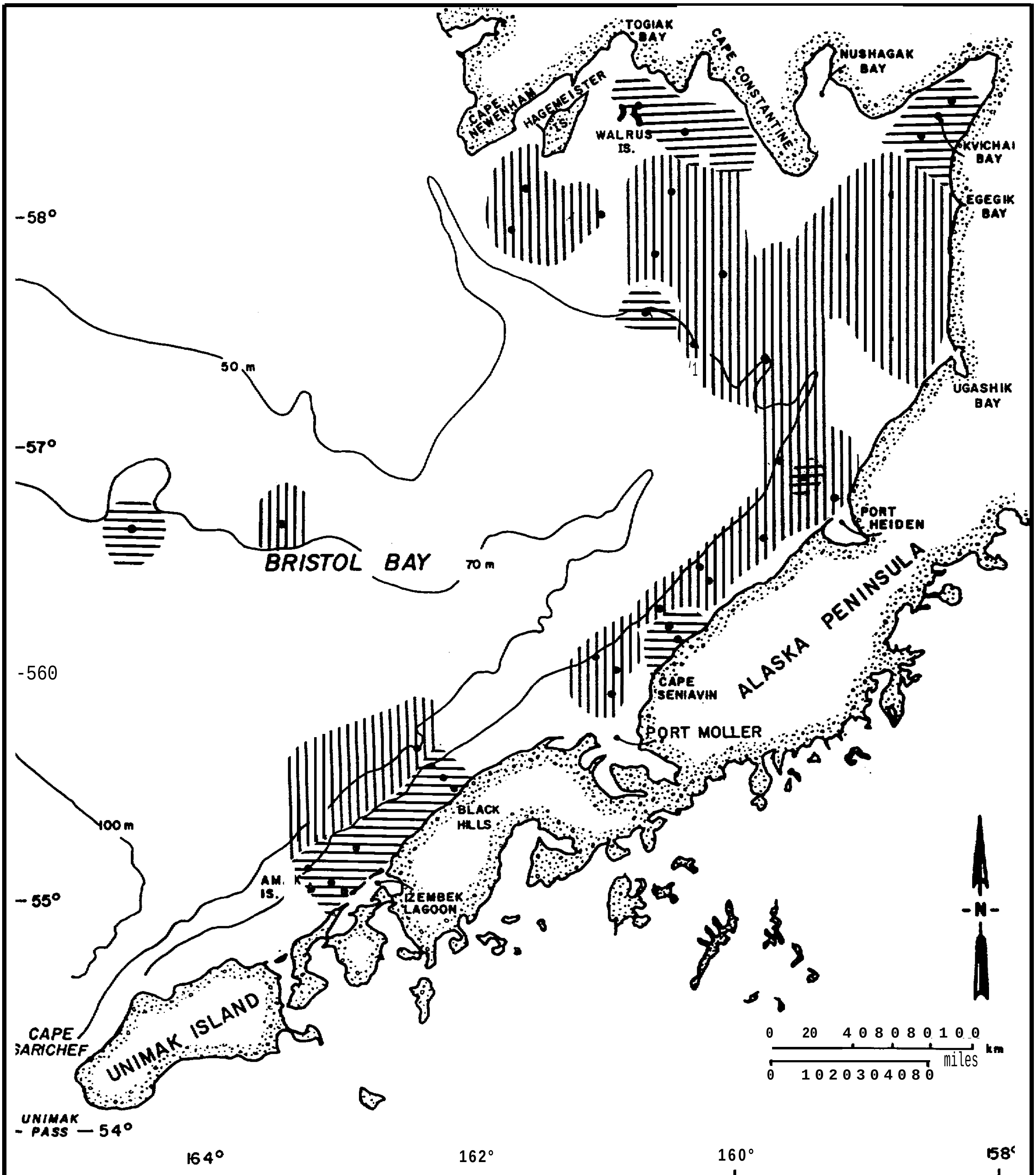
X = **OFFSHORE** ASSEMBLAGE

= TRYNET SAMPLING STATIONS, ALL CRUISES COMBINED

BRISTOL **BAY**
RED **KING CRAB**

DISTRIBUTION OF TRY NET SAMPLE GROUPS FROM CLUSTER ANALYSIS

FEBRUARY 1984 | **FIGURE** 3.7-1



= GROUPS A, B

= GROUPS C, D

• = ROCK DREDGE SAMPLING STATIONS, ALL CRUISES COMBINED

379

BRISTOL BAY
RED KING CRAB

DISTRIBUTION OF
ROCK DREDGE SAMPLE **GROUPS**
FROM CLUSTER ANALYSIS

FEBRUARY 1984 | FIGURE 3.7-2

group AB, especially the fish species. They were characterized by a number of invertebrates," including urchin (*Strongylocentrotus droehbachiensis*), a hermit crab (*Pagurus beringanus*), sea star (*Henricia* sp.) and gastropod. Small juvenile red king crabs, ages YOU and O+ through 1+, were fond primarily in the group CD samples, whereas older juveniles were found primarily in group AB samples.

SECTION 4.0

DISCUSSION

4.1 Larval Distribution and Abundance

4.1.1 Interannual Comparison of Larval Abundance

The extensive discussion of larval population dynamics given by Armstrong, et al. (1983b) presented evidence that larvae are distributed nearshore along the NAS in most years, are virtually absent offshore over the middle and outer shelf domains, and are present but poorly studied in Inner Bristol Bay. By comparing larval data sampled in successive years along the NAS, it was found that larval densities in the western region* were generally low in recent years. In the years 1976 and 1977, larval densities were high at a mean value of 13,200 larvae per 100 m^2, but in the years 1978 to 1982 were 400 to 700 per 100 m^2 (Armstrong, et al. 1983b). These authors suggested that the reduction in larvae along the western NAS had been caused, in part, by a shift of mature females offshore and to the east in the southeastern Bering Sea, and by a reduction in the female population. Again in 1982, mean larval density throughout subarea IL was low, 440 per 100 m^2, due in part to a large number of zero stations in very shallow water (<30 m) and off Unimak Island (Figure 4.1-1). However, densities were very high along the 50 m isobath from Izembek Lagoon to Black Hills with a mean of 2,600 larvae per 100 m^2. Densities *were* uniformly high in subarea PM (Port Moller) in 1982 where the mean density was 7,800 per 100 m^2.

In marked contrast, larval densities in June 1983 throughout all of subareas IL and PM over a distance of 300 km were the lowest yet. calculated, including information from 1969 and 1970 (Haynes 1974). A mean

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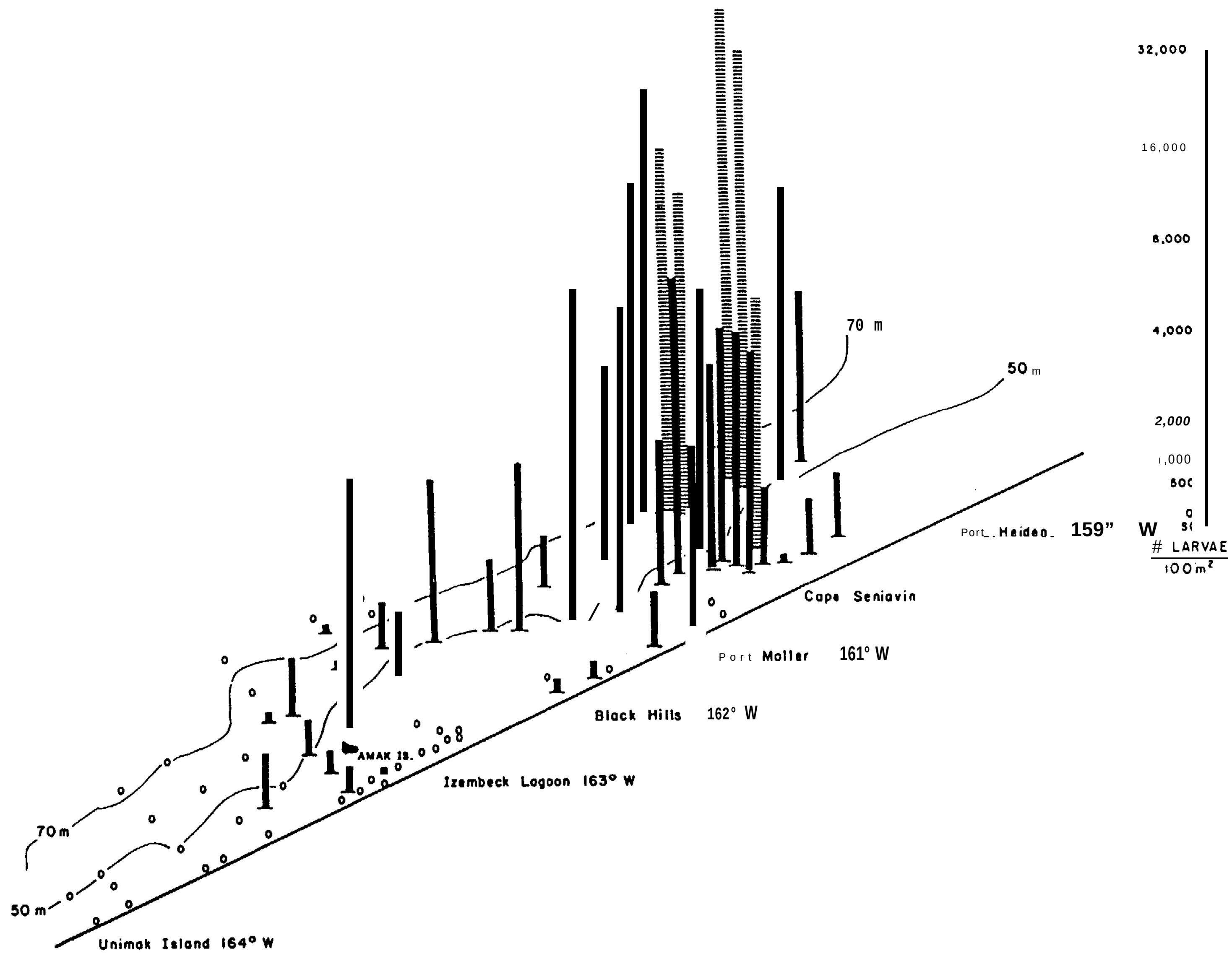
* This area extends west from 162°W longitude at Black Hills and is defined as subarea IL (Izembek Lagoon) in the present study.



NOTE: Longitudes of Shoreward Stations are approximate.
Difference in appearance of bars is for visual aid only.

BRISTOL BAY
RED KING CRAB
LARVAL DENSITIES
DURING JUNE 1982

FEBRUARY 1984 FIGURE 4.1-1

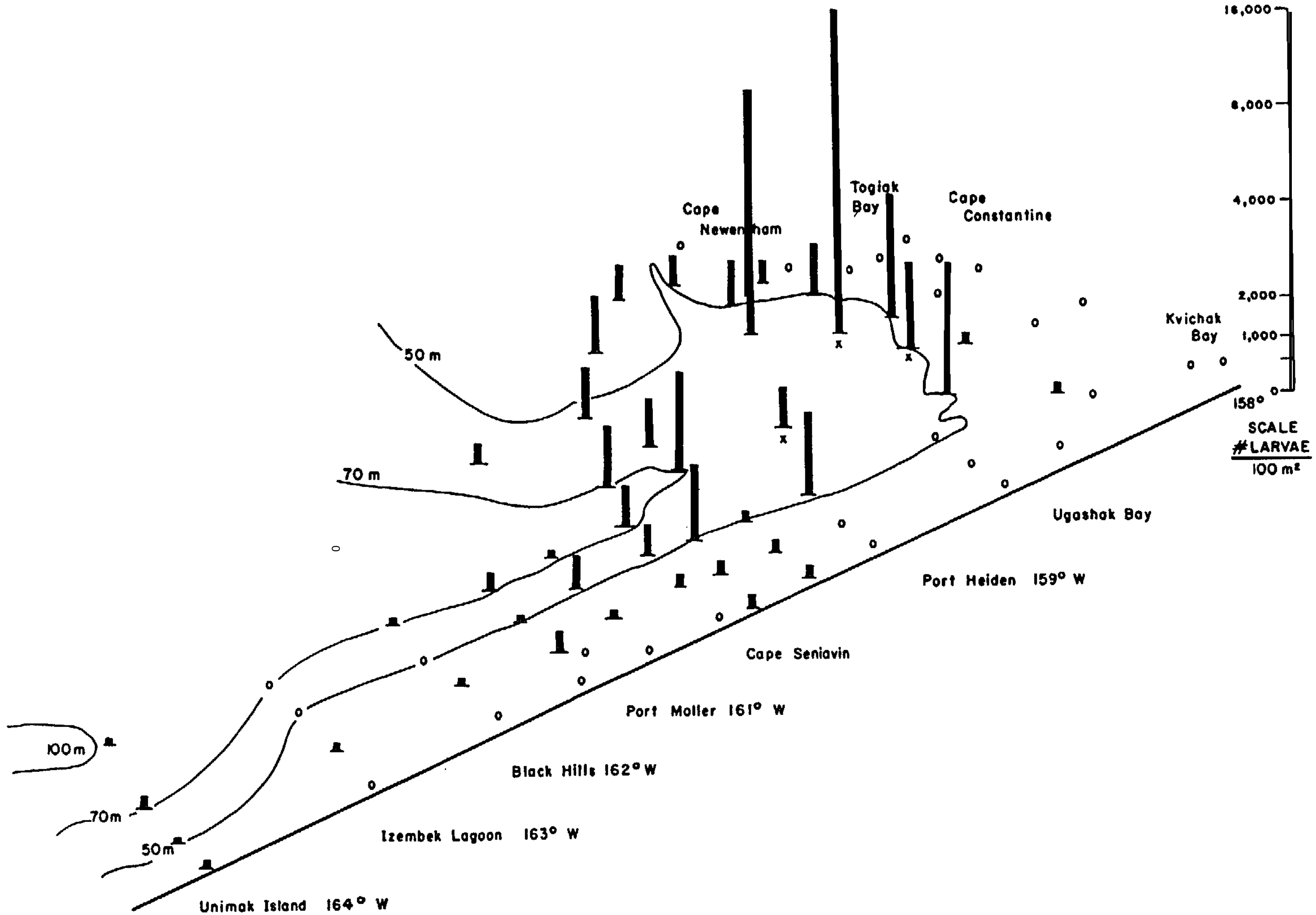
density of 43 larvae per 100 m^2 was derived for subarea IL, and 230 per 100 m^2 was the mean off Port Moller (Figure 4.1-2),

This 33-fold reduction in NAS larvae in 1983 was a persistent feature along the entire nearshore survey area during June, and suggests that either substantial reproductive failure and/or inordinate larval mortality occurred along the nearshore perimeter of the southeastern Bering Sea population, or that this area is not as important to species propagation as previously argued by some authors (Armstrong, et al. 1983b). The only substantial numbers of larvae found in June 1983 were offshore between 50 and 70 m over strata IB of Inner Bristol Bay where the mean density was 2,100 larvae per 100 m2 (Figures 3.2-2 and 4. 1-2). Considering previous evidence of moderate to high larval densities in this area (2,000-10,000 per 100 m^2; Armstrong, et al. 1983b; Haynes 1974), the importance of offshore central Bristol Bay as larval spawning ground should be reconsidered.

4.1.2 Female Stocks, Larval Hatch and Transport

The dilemma faced in assigning great importance to offshore areas as spawning habitat is to make the spatial connection between the occurrence of pelagic larvae there and the areas of apparent larval metamorphosis and settlement to the benthos as defined in this study. During a previous decade of NMFS groundfish surveys throughout the southeastern Bering Sea, 0+ and 1+ crab were virtually never taken in benthic trawls. Armstrong et al. (1983b) speculated that this fai 1 ure to catch very young age groups was the result of either large, ineffective gear (for such small crab) and/or minimal effort in nearshore areas where larvae were hypothesized to settle given patterns of "pelagic distribution.

Small juvenile crab ($\leq$10 mm) were caught in April, June and September 1983 (see Section 3.4). Small crab taken in April were certainly of the 1982 0+ year class, those in June questionable, and the large numbers of



NOTE: Longitudes of Shoreward Stations are approximate.

BRISTOL BAY
RED KING CRAB

LARVAL DENSITIES
DURING JUNE 1983

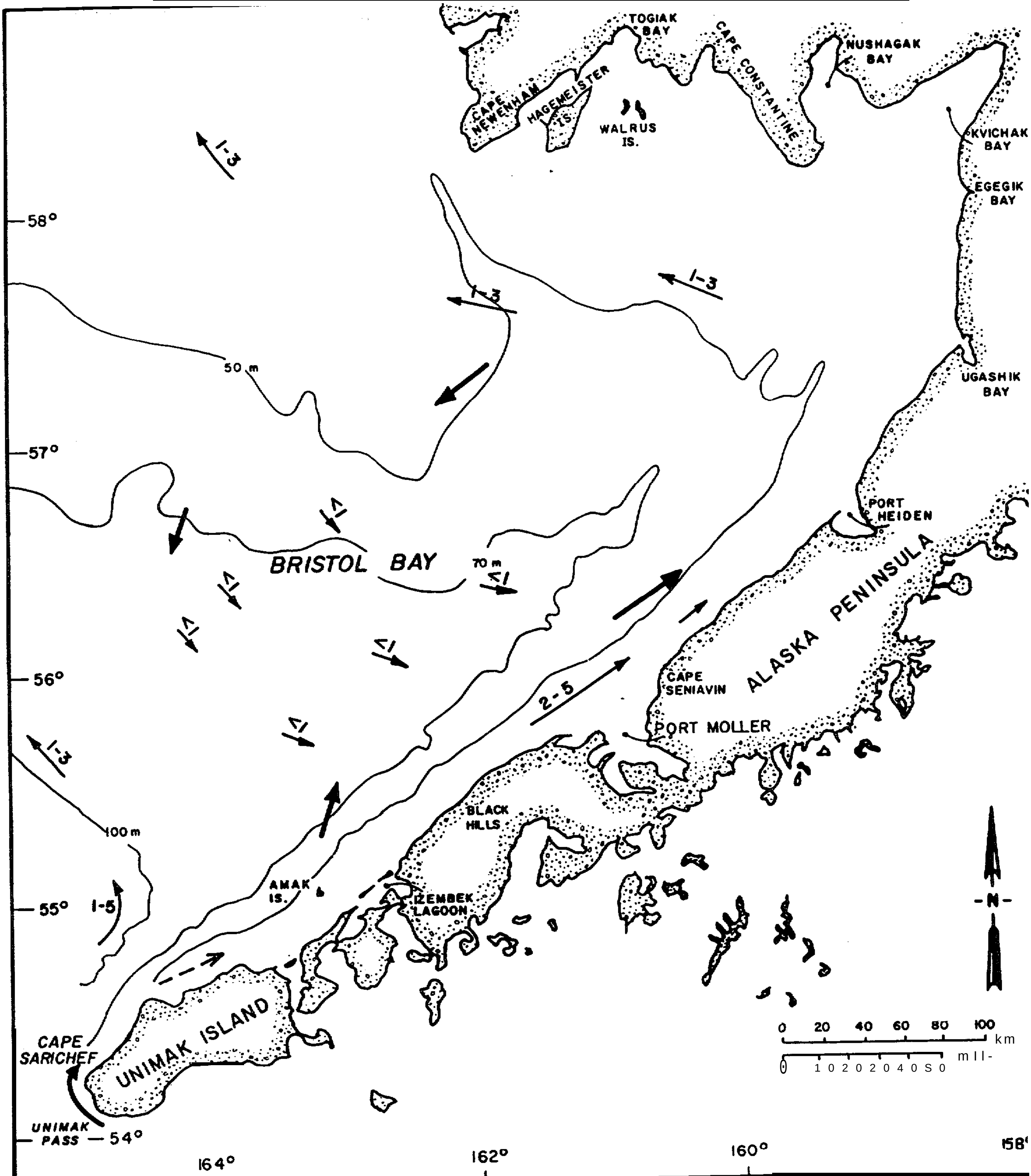
FEBRUARY 1984 FIGURE 4.1-2

about 5 mm carapace length caught in September were undoubtedly 1983 young-of-the-year crab. In all months, small juveniles were usually found inside the 50 m isobath where larvae were rare in 1983, but common in previous years. It is not difficult to imagine that nearshore 0+ juveniles are the survivors of nearshore larvae, entrained and transported in slow, longshore currents (Figure 4.1-3) that move counter-clockwise to the northeast into Bristol Bay (Kinder and Schumacher 1981b; Schumacher and Reed 1983). Larvae settle out of this current at fortuitous points along the NAS based on rates of development, but likely survive only in areas where appropriate substrate affords refuge (off Port Moller, Cape Seniavin, Port Heiden, Kvichak and Togiak Bays).

The origin of larvae in high abundance between 50 to 70 m is uncertain. Possibly they were hatched between Black Hills and Cape Seniavin in early May, and were transported north-northeast in prevailing currents. Water conditions in June showed two pockets of colder water (5°C or less) at points along the 50 m isobath north of 57″N that may have funneled warmer coastal water between Cape Seniavin and Port Moller offshore (Figure 3.1-8). Or as suggested previously, larvae in this area were hatched later than those nearshore and were a separate, more abundant cohort. The arguments in favor of an offshore cohort are: 1) colder bottom water temperatures (Figures 3.1-10 and 3.1-11) that may have slowed somewhat the rate of egg development and thus delayed hatch; and 2) the greater proportion of younger S11 and S111 larvae found in this region (subarea IB; 50 m isobath border of TB) than elsewhere throughout the study area where S111 and SIV were common (Figure 3.2-3).

Larvae hatched offshore between 50 and 70 m in inner Bristol Bay were more difficult to account for as benthic 0+ juveniles in shallower water and, in fact, such larvae (and the spawning females) were thought to be superfluous to annual reproductive effort by Armstrong, et al. (1983b).

This notion was based on models of current speed and direction that considered the water of the eastern middle shelf domain to be essentially static with virtually no net direction (Kinder and Schumacher



NET CIRCULATION IN CM s^{-1} (KINDER & SCHUMACHER (1981)

INTERMITTENT CIRCULATION (KINDER & SCHUMACHER 1981)

NET CURRENT (HEBARD 1959)

BRISTOL BAY
RED KING CRAB

KNOWN CIRCULATION
PATTERNS IN BRISTOL BAY

FEBRUARY 1984 FIGURE 4.1-3

1981b). Larvae hatched in this region would be expected to develop and settle out essentially in the same area as the origin of hatch; an area which may not be amenable to survival of small juveniles.

The notion of a confined water mass with no component of lateral transport must not be correct, or the process may not be operative in all years. Despite the near absence of larvae nearshore in June 1983 (Figure 3.2-2 and 4.1-2), young-of-the-year juveniles were found three months later in Kvichak Bay about 150 km northeast of the center of offshore larval abundance (Figure 3.5-6). Juvenile settlement in an area far removed from the apparent centers of larval hatch in 1983 and in an area more or less "up current" from central Bristol Bay, argues that a model of a rigid, cold water mass that guides but does not exchange with a nearshore counter current is inappropriate for the observed phenomena in upper layer water.

The relationship between female stocks and the magnitude of recruit populations has never been well defined for red king crab. Reeves and Marasco (1980) hypothesized that: 1) high female abundance and full copulation is not required for maximum recruitment, but; 2) mature female abundance could decline beyond a level such that recruitment is reduced. This theoretical female population size is about 20 million based on their analyses. Armstrong, et al. (1983b) added that the total population of females in the southeastern Bering Sea may not be so important a gauge of potential recruitment as is the size of regional populations where larvae have the greatest chance of settlement to optimal substrates. As they pointed out from NMFS data, mature female populations declined in the southeastern Bering Sea between 1977 and 1981 and became less common in nearshore, warmer water habitats. This trend has continued in 1982 and 1983 as mature female populations have declined to 55 million and 10 million, respectively, presently a level below Reeves and Marasco's theoretical recruitment optimum. Nearshore abundance has further declined such that ovigerous females were rather rare along the entire North Aleutian Shelf from Unimak Island to Kvichak

Bay and west to Cape Newenham. The 1983 population was centered over Bristol Bay between 50 to 70 m and, in general, reflected closely the abundance of larvae in the water column.

4.1.3 Vertical Distribution

The May time series demonstrated the presence of diel vertical migration in first stage red king crab zoeae. This behavior had been suggested previously (Takeuchi 1962, trans. 1967; Haynes 1977), but not quantitatively documented. Kurata (1960) has suggested that if larval red king crab vertically migrate, there should be less vertical migration in the later stages as they adopt a more benthic behavior. No support was found for any changes in vertical migration for the first three zoeal stages.

Diel vertical migration in larval decapods may have an important effect on the horizontal distribution of these stages, particularly in areas where current direction and/or velocity change with depth. Larval blue crabs (*Callinectes sapidus*) vertically migrate and are thus retained in Atlantic Coast estuaries where habitat is suitable instead of being dispersed into the open ocean (Sulkin and Van Heukelem 1982). Epifanio and Dittel (1982) hypothesize that successful recruitment of *C. sapidus* is due to "the evolution of behavioral traits (i.e., rhythmic vertical migration) that allow larvae to take advantage of . . . advective flows." Cronin and Forward (1982) further argue that such rhythmic behavior may be widespread among estuarine planktonic larvae, particularly where tides exert strong dynamic effects.

Rhythmic vertical migration in larval red king crabs may have similar biological significance. Hebard (1959) reported that currents in the shallow Bristol Bay region are strongly influenced by tides. He further learned that surface and bottom currents there flow in different directions. Since red king crabs dwell primarily in and apparently evolved in shallow Alaskan coastal waters (Makarov 1938) which are characterized by strong tides, then similar larval behavioral traits would have a similar biological significance.

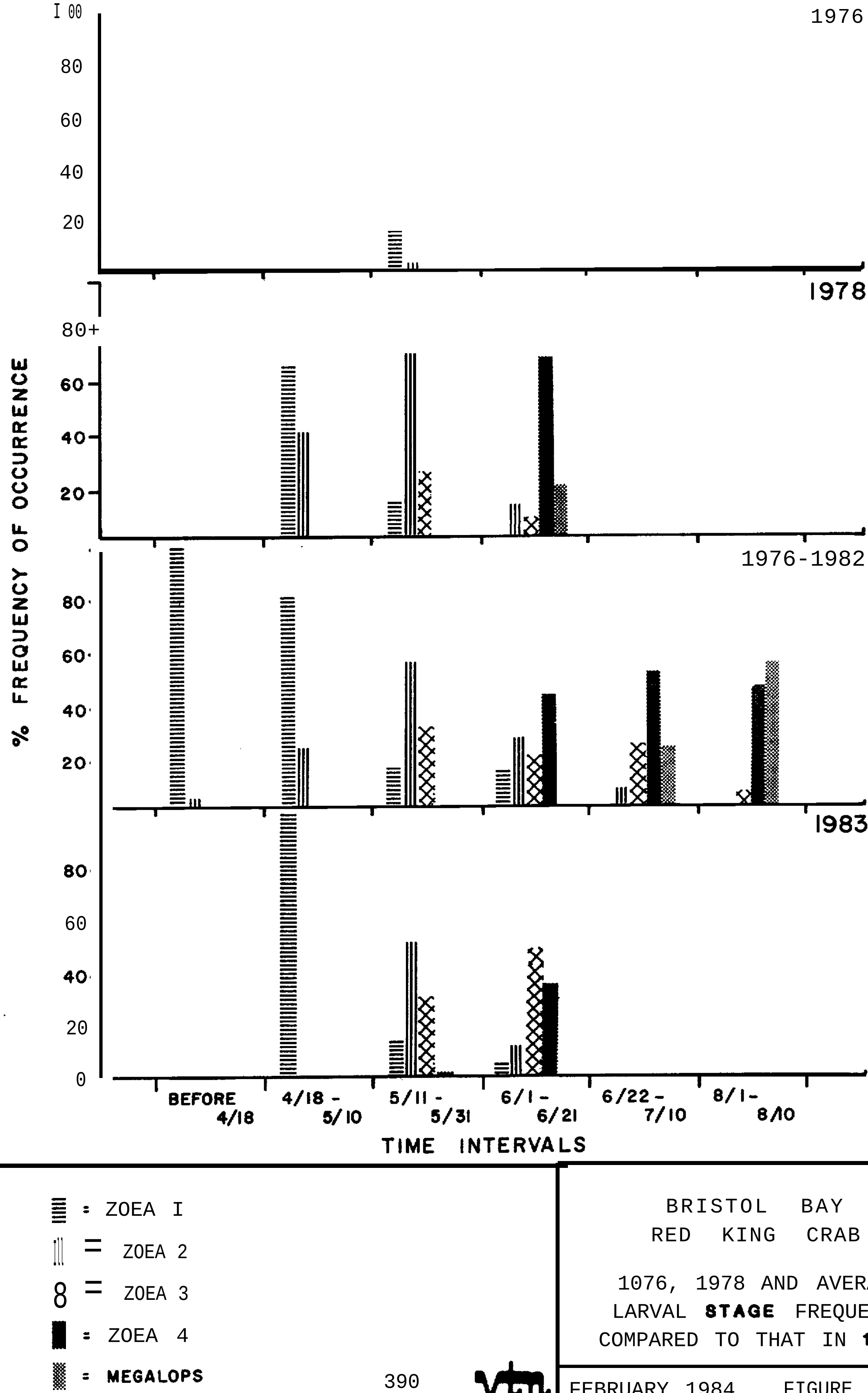
4.2 Interannual Larval Hatch and Development

Although the larval hatch and release was late this year when compared to the average for red king crab in Bristol Bay found by Armstrong, et al. (1983b), it was not the latest recorded. The 1976 release was after 10 May, and the timing of development for 1983 was very similar to the 1978 release (Figure 4.2-l). The 1982 release may also have been similar to 1978 and 1983 in timing; however, sampling was too late last year to be strictly comparable.

The most apparent aspect of Figure 4.2-1 is the highly variable timing between years of the initial hatch release. Physical factors, such as water temperature, are likely the cause of the five plus week difference in timing between releases. This hypothesis finds further support in a recently released U.S. NOAA Weather Service report on this past decade's . weather. According to this report, the past ten years, covering the period studied by Armstrong, et al. (1983b) and this investigation, has been one of the most variable decades for weather ever measured, with three of the warmest years and three of the coldest years on record. If water temperature or another physical factor is the cause of the differences in timing, then the variations in timing of larvae release may be due to such variability in weather patterns.

4.3 Post-larval Size and Age Distribution

In the southeastern Bering Sea the time of appearance of the first red king crab juvenile stage varies over four to six weeks after hatching, with peak settlement in early July near Unalaska and mid-August in Bristol Bay (Weber 1967). Juvenile growth progresses from between 2.6 and 3 mm at settlement to an average of 11 mm at 12 months after settlement. Development during this time progresses through eight (Powell



BRISTOL BAY
RED KING CRAB

1076, 1978 AND AVERAGE
LARVAL **STAGE** FREQUENCY
COMPARED TO THAT IN **1983**

FEBRUARY 1984 FIGURE 4.2-1

1967) to 11 molts (Weber 1967). The differences in growth rate induced by changes in the early molting frequency data on young crab are great; therefore, it is important to obtain accurate molting frequency data on young crabs.

The September 1983 sampling demonstrated an absense of larvae in the zooplankton samples and a dominance of YOY individuals. This reflects recent (2-4 weeks earlier) mass metamorphosis of larvae into benthic-dwelling juveniles. Although most first post-larvae appear in the southeastern Bering Sea from mid-July through mid-August, minor settlement occurs before and after this time. The few O+ (4-6 mm) in the April-May and June sampling are presumably individuals that had settled late, in August or September 1982. A late hatching cohort would most likely lead to settlement as cold bottom water temperatures begin and thus growth to 4-6 mm by the following spring might be expected.

Relatively moderate numbers of age 1 and 1+ crabs were found during the April-Nay and June cruises; somewhat greater numbers of these age groups were found during September, indicating recruitment from the 1982 YOY group. The very low numbers of age 2 and 2+ crabs in the samples may be explained by the highly clumped distribution resulting from podding behavior. Apparently crabs younger than approximately age 2 (≤28 mm) do not stray far from the protection of their settling location. The first year of benthic life is spent in rocky crevices, kelp patches, among colonies of tube worms, and other protective niches. Between the ages of 12 and 24 months, juvenile crabs abandon their numerous hiding places and congregate to form pod communities (Powell and Nickerson 1965; Powell 1974). The small aggregations of the youngest crab often disband and seek refuge in the surrounding substrate. As they age there is a tendency to remain in a pod formation for longer intervals.

Pod formations are analagous to other animal congregations such as herds, flocks and schools. Podding describes the general behavior of young crabs in forming contact aggregations which is believed to provide protection against predators, as well as to organize the crabs into a coordinated group, so that, acting as a unit rather than as individuals, they can benefit from their coexistence (Powell 1974). The following is an account of a pod observation near Kodiak Island (Powell and Nickerson 1965):

> "On two occasions elongated dome-shaped piles of crabs were observed lying parallel to the beach at depths of four to 35 feet. These piles appear to be numerous pods joined in a line. On February 19, 1961, the first group of an estimated 6,000 crabs averaging 30 mm was observed and described in field notes as a long windrowed pile. A similar observation on April 25, 1962 revealed an estimated 500,000 crabs 34 to 98 mm in carapace length having modes at 61 and 84 mm. One foot from an end of the 12-foot zig zag pile was a pod of approximately 1,000 crabs, giving rise to the idea that spherical pods form elongate piles when they congregate. Thousands of other crabs remained scattered and feeding."

Pods have been observed during every month of the year, and all of them contain both males and females of similar size and of the same age. Most podding crabs are between 2 and 3+ years old (29-73 mm), although the above observation testifies that crabs with a mode of 84 mm were one of the two distinct size classes in a pod.

Few pod-sized crabs (29-73 mm) were collected during the three sampling periods of 1983. During the April-May and June sampling, age 2 and 2+ crabs were rarely found. However, ages 3 and 3+ were more numerous, mainly occurring at deeper stations (stations TB350, TB550, BB557 and PH350) than the previous age group. In September, ages 2, 2+ and 3 were absent and only one age 3+ crab was found. The data collected do not indicate that crabs were sampled while podding. Although each station was briefly sampled, it is expected that if a pod was sampled there would be a high number of similar-sized individuals. Among those stations that yielded pod-size crab both the quantity and the proportion at podding size were low. Presumably the lack of pod-size crab in September is a reflection of the lack of effort in central Bristol Bay, however, it may also be due to their patchy transient nature. Podding has been documented on the North Aleutian Shelf near Akutan and Unalaska

Islands (Powell and Nickerson 1965; Weber 1967). During the year of sampling near Unalaska, several groups of king crabs 29-69 mm were not sampled continuously and were interpreted as being transient.

4.4 Post-larval Distribution and Abundance

The distribution of red king crabs age YOY to three years was generally restricted to the coastal domain of the North Aleutian Shelf and Bristol Bay, the area landward of the 50 m isobath. This area had the lowest bottom salinities (≤ 26 ‰), highest bottom water temperatures (>11°C by September) and the largest grained sediments sampled in the study area.

YOY crabs occurred from waters north of Izembek Lagoon (station IL430), northeasterly along the coast and into Togiak Bay in the north. Densities were greatest in the Port Heiden and Kvichak Bay areas. These results agree with settlement areas as projected from previous larval king crab studies. Haynes (1974) reported that under the generally cyclonic (counter-clockwise) water movement in the southeastern Bering Sea, larvae released in the Black Hills-Port Moller area were carried northeastward along the Alaska Peninsula toward the head of Bristol Bay. The pattern of larval distribution described for 1983 showed concentrations of newly released larvae off Port Moller in nearshore (<50 m) waters and also in central Bristol Bay in mid-depth (50-70 m) waters. By June, the greatest concentrations were found roughly parallel to the 50 m isobath from the Port Moller-Port Heiden sampling areas boundary north and west to the edge of the study area. The greatest larval concentration was in the mid-depth (50-70 m) water between Port Moller and Cape Newenham (see Figure 3.2-2).

All YOY juveniles were found on gravel or larger sized substrates. These substrates were similar to those inhabited by early juvenile king crab of lower Cook Inlet and Kodiak Island (Powell, et al. 1974; Sundberg and Clausen 1979). YOY apparently depend on an environment which provides for adequate food (i. e., hydroids and bryozoans) and protection from predators (see discussion in Armstrong, et al. 1983b). The distribution of such suitable substrates in the study area was extremely patchy and it is believed that settling in areas where such substrates are absent or limited would hasten natural mortality.

The substrates inhabited by juvenile red king crabs during this study also supported a characteristic attached invertebrate fauna, primarily stalked sea squirts (Boltenia ovifera), bryozoans, and colonial tube-dwelling polychaetes in the Kvichak Bay area. Although it appears that a direct relationship exists between the distributions of red king crabs and certain attached epifaunal taxa, the relationships are not yet clearly defined. Samples of Boltenia ovifera, for example, indicated that their greatest concentration was in the 50-70 m deep area of the inner Bristol Bay sampling subarea; no red king crabs younger than age 3+ were found in this area, even though this was the area of greatest pre-settlement larval concentrations during June.

Although YOY in the present study were found in depths of 20-50 m, successful settlement is known to take place in shallower as well as deeper waters. In Kodiak Island waters, young crabs one to 12 months old were commonly found in the littoral zone (Powell and Nickerson 1965). The maximum depth at which post-larval crabs smaller than 16 mm have been captured was 106 m off Kodiak Island (Powell and Nickerson 1965). The Japanese king crab tangle net fishery in the eastern Bering Sea from 1956 to 1959 captured 5,495 juvenile crab from 2 to 33 mm carapace length (INPFC 1960). They were caught 139 to 213 km northwest and seaward of Port Holler, at an average depth of 55 m.

The hypothesis that post-larval survival is related to settlement onto appropriate "refuge" habitat (Armstrong, et al. 1983b) is supported by the apparent distribution of juvenile crabs found in this study. This refuge habitat is thought to consist of gravel or larger-sized substrates inhabited by any of several attached epifaunal invertebrate species. The attached invertebrate fauna may, in fact, be the most Important aspect of the habitat, for very few juvenile crabs were found in samples of bare gravel. Shipboard substrate preference tests were conducted with age 1+ crabs during the June cruise (see Appendix F). While far from conclusive, the tests indicated that in the absence of epifauna, young crabs preferred a medium-sized rock substrate over small rock, gravel or sand. When small "reefs" of natural epifaunal material were placed on the previously bare substrates, the highest percentages of crabs were found on tube worms/sand and mussels/small rock combinations. The erect bryozoan/ medium rock combination attracted the smallest percentage of crabs. Crabs were observed during the experiments feeding directly on the tube worms and scavenging food from the spaces between mussels.

Further studies are needed to test the relationship between post-larval survival and refuge habitat. The successful settlement of young-of-the-year crabs during 1983 was apparently on the habitats described in the Port Heiden and Kvichak Bay sampling areas. These areas are on the edge of the area of apparent maximum larval concentration found during June.

Larval transport by water currents is the apparent mechanism determining the distribution of premetamorphic king crab larvae (Armstrong, et al. 1983b; Haynes 1974; Hebard 1959) . It is possible that larvae are transported by near-surface as well as bottom currents, as indicated by the diurnal vertical distribution patterns found during this study (Section 3.2.2). The appearance of young-of-the-year king crabs in the Port Moller-Port Heiden area between June and September is easily explained using the available current data that show a slow counter-clockwise movement along the North Aleutian Shelf (Haynes 1974). More difficult to explain is the occurrence of young-of-the-year crabs in the upper reaches of Kvichak Bay since pelagic larvae were not found in that subarea. No current data are available for Kvichak Bay except the general westward drift of low salinity surface water originating primarily from the Kvichak and Nushagak Rivers.

4.5 Potential Effects of Oil and Gas Development

Theoretical considerations of potential oil and gas development impacts on marine species have been discussed previously for the St. George Basin (Hameedi 1982) and the North Aleutian Shelf (Thorsteinson 1983) in the southeastern Bering Sea. Several workshops held at Asilomar, California (1980) and at Anchorage, Alaska (1981, 1982) considered the impact of oil in this region on commercial crustaceans, notably Tanner crab and red and blue king crab. Largely as a result of these meetings at which biological information on the species was summarized in regards to potential oil impact, shortcomings in available information crucial for oil impact assessment were identified and projects such as the present study were initiated. Consequently, literature dealing with potential hydrocarbon impacts on crab and shrimp of the southeastern Bering Sea has been reviewed several times over recent years (Armstrong, et al. 1981a, 1983a,b; Curl and Manen 1982). These reviews have considered both the physiological/biological sensitivity of crustaceans to hydrocarbons and the ecological vulnerability of selected species. The following discussion is limited to potential impacts of oil spills.

A consensus that red king crab along the NAS and blue king crab around the Pribilof Islands are species of high ecological vulnerability (Armstrong, et al . 1983a) prompted OCSEAP to support research that would better portray the general ecology of these species (e.g., distribution and abundance over different substrate types), and establish links between the population dynamics and year class strength of larvae, juveniles and mature females. As noted by Armstrong, et al. (1983b), the relative interannual variability in temporal and spatial population dynamics of larvae should be considered in terms of: 1) female stocks as the origin of hatch; and 2) young benthic juveniles as the final location of pelagic survivors. This theme has been expanded in the current study and serves as a basis for discussing potential oil impacts to red king crab in the NAS-Bristol Bay region.

The approach taken in this analysis is one that considers major life history stanzas of the species in regards to important biological and ecological traits, and discusses the modes and extent of oil pollution as it may affect these stages. Use of life history stanzas is considered a sound categorical division for comparing and contrasting physiological, reproductive and ecological changes that occur during a life cycle (Wooster 1983). Armstrong, et al. (1983b) have provided a review of oil impact literature and interpreted their data in light of these life history stanzas. The assertions and hypotheses of Armstrong, et al. (1983b) have been modified in accordance with the field data acquired during the present study.

4.5.1 Oil Transport Models and Impact Scenarios

Before relating the biology of red king crab to predictions of oil impact, it is important to first discuss the physical transport of oil both horizontally and/or vertically by currents, winds and biological processes. A brief recount of oil impact scenarios used at OCSEAP synthesis meetings will illustrate the locations and magnitude of oil pollution considered to be representative of possible spills along the NAS and in the St. George Basin. These scenarios will serve as a point of reference in framing estimates of species' vulnerability based on data in this report.

Two models of physical transport processes, water movements and biological interactions and responses to oil in the Bering Sea have been constructed (Leendertse and Liu 1981; Sonntag, et al. 1980). Several models of water transport and circulation have been based on net current directions and velocity (Hebard 1959; Kinder and Schumacher 1981b), and on methane profiles (Cline, et al. 1981).

Hebard (1959) described currents moving to the northwest through Unimak Pass, with a component then moving northeast along the North Aleutian Shelf. Although the direction of the current is highly variable and to a great extent tidally driven, there is a net movement of 2.0-5.5 cm see-l eastward and northward into Bristol Bay. Kinder and Schumacher (1981b) and Schumacher and Reed (1983) summari zed data for current patterns in the southeastern Bering Sea and showed weak currents of 2-5 cm see-l along the NAS and 1-5 cm see-l moving northwest over the St. George Basin (Figure 4.1-3). They stressed that instantaneous flow can be substantially greater than these averages (up to twenty times greater than the long-term vector) and the direction quite variable. Cline, et al. (1981) used methane profiles to calculate current speeds of 7 cm see-l northeast along the NAS and 5 cm see-l northwest over the St. George Basin. Both values are in close agreement with current meter readings.

In the area of the present red king crab study, Bristol Bay encompasses two well-defined water masses separated by a frontal system at approximately the 50 m isobath (Figure 4.1-3; Iverson, et al . 1979, Kinder and Schumacher 1981b) . Shoreward of the 50 m isobath is the coastal domain where waters are vertically homogeneous and turbulent due to wind and tidal mixing. There is little horizontal mixing across the density gradient of the frontal system, particularly at depth, but surface waters of the coastal domain may deviate from a strict counter clockwise pattern to move northward across the middle shelf domain in summer (L.K. Coachman, Dept. Oceanography, U. W., pers. communication).

The middle shelf domain between 50 and 100 m is characterized as a stratified two-layered system of cold residual water that is heated and mixed to variable depths by radiation and wind in the spring and summer. This water mass is portrayed as an essentially stationary barrier that deflects coastal currents to the northeast toward Kvichak Bay and then west to' Cape Newenham.

The physical properties-of these water masses in regard to temperature, food supply, and rate and direction of currents are of major importance for assessing their relative value to larval production and survival.

Such information can be used to gauge the movement of crab 1 arvae in currents rel ative to origins and surface speeds of oil movement. These exercises have been done by Leendertse and Liu (1981) and Sonntag, et al. (1980).

Following hypothetical oil spills or well blowouts in these models, oil is moved by winds and currents, mixed by storms, and transported to the benthos by several processes. It may then impact crab populations by direct exposure, loss of food and over-competition, or accumulation in tissues and gametes. Oil concentrations in the water column and benthic sediments are modeled as a function of the magnitude of an initial oil spill and its duration, time of year, location, and loss of certain oil fractions by processes such as volatilization. Model outputs show the trajectory and extent of oil coverage and concentration at various times after each hypothetical mishap. From data and assumptions on lethal levels, distribution and abundance of animals, sensitive life-history stages and physiological events (e.g., molting of crustaceans), predictions are made of the proportion of a year-class or population killed and the eventual ramifications such losses pose to commercial fisheries.

Scenarios considered by participants of the 1981 Anchorage OCSEAP Workshop included only spills or blowouts that released 50,000 barrels (bbl) which is a quantity far 1 ess than might be expected from mishaps involving modern tankers. Oil spill in scenarios used during the North Aleutian Shelf synthesis meeting in Anchorage (March 1982) were even smaller. Spil 1s of 10,000 bbl were modeled by Pel to and Manen (1983) and covered relatively small areas of the NAS (20 km by less than 1 km).

Spill scenarios modeled by the 1980 Asilomar Workshop included both a 100,000 mt (1.11 x 10^6 bbl) spill over two days and a release of 5,000 mt day^{-1} (55,500 bbl) for 20 days (Sonntag, et al. 1980). After mixing oil to 50 m depth and a loss of 25 percent of the volatile fraction, an area of 7,500 km2 was polluted at or above 0.2 mg l^{-1} (considered a lethal threshold in that model). If as suggested by Armstrong, et al.

(1983 b), the same volume of oil is mixed to 20-30 m and 0.05-0.1 mg l^{-1} is considered toxic to crab larvae, then an area of 15,000 km^2 might be affected. Curl and Manen (1982) predicted that a 50,000 barrel spill in the St. George Basin would be lethal over a 100-300 km^2 area (0.2 mg l^{-1} threshold; mixed to 50 m). In a worst-case scenario, mixing oil less deeply and considering oil concentrations of 0.05-0.1 mg l^{-1} water Soluble fraction (WSF) to be toxic, then water over an area of 10,000-15,000 km^2 might contain concentrations toxic to crab larvae following a large spill.

In order to study the direction of surface oil trajectory following oil spills from lease sale areas in the SEBS (Figure 4.5-l), Leendertse and Liu (1981) ran computer simulations based on average wind events in winter and in summer (Figure 4.5-2). During summer and fall, oil from spills in the St. George Basin and along the NAS would be moved by prevailing winds east over the middle shelf and south to the North Aleutian Shelf coast at Unimak Island eastward for 200 km (Figure 4.5-2A). In the winter, oil would be transported northwest off the shelf or towards the Pribilof Islands (Figure 4.5-2B). Most sigificantly, the rate of movement in summer is predicted to be about 8.5 km day^{-1}, much faster than the net current transport of crab larvae along the NAS, which is estimated to be between 1.4 and 3.4 km day^{-1}. Further, surface borne oil can be moved east by winds over the surface of the middle shelf domain to the coastal domain, even though the water masses exchange very little water through advective processes. Easterly movement of oil from the NAS lease sale area in late spring and summer would move hydrocarbons towards major population centers of all red king crab life history stanzas.

4.5.2 Oil Toxicity to Red King Crab Life History Stanzas

The king crab life history stanzas covered in this analysis are: 1) sexually mature females; 2) developing eggs; 3) pelagic larvae; and 4) young juveniles as 0+ (including young-of-the-year) to 2+ age groups.

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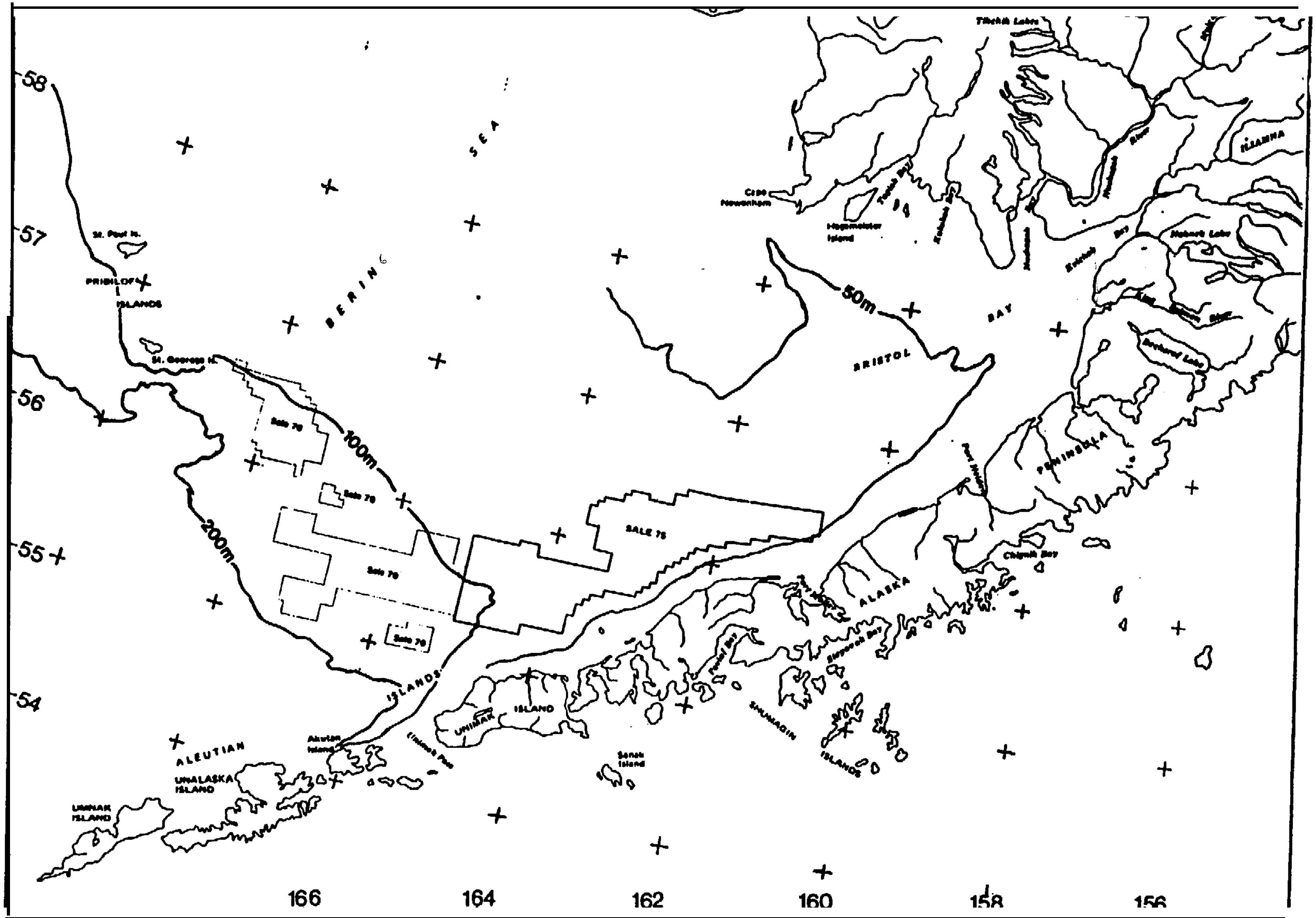
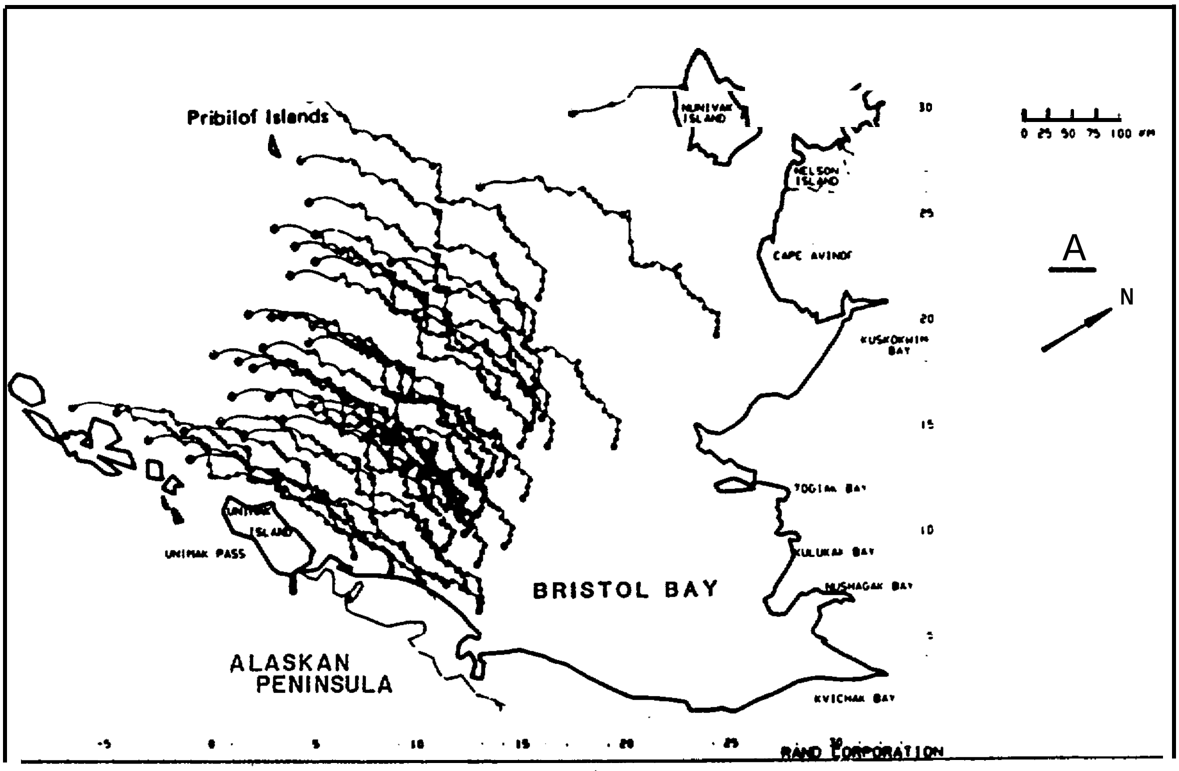
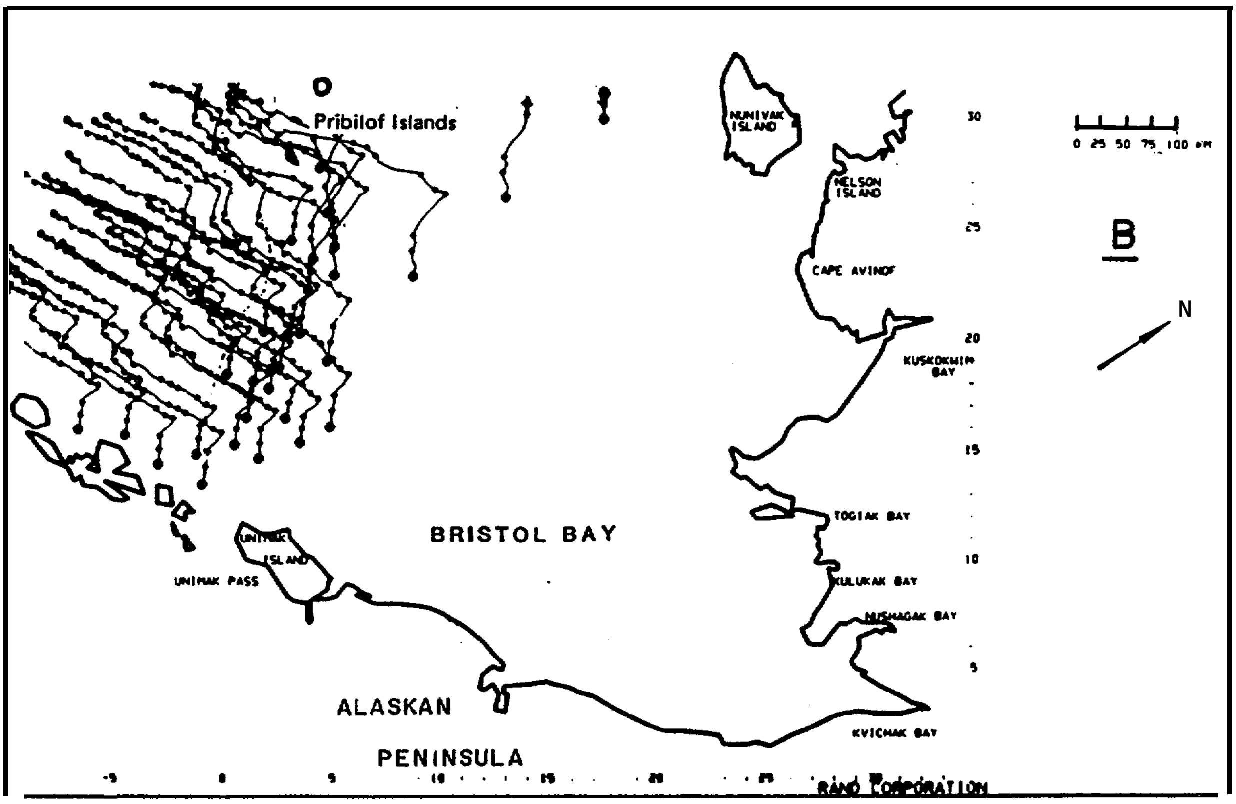


BRISTOL BAY
RED KING CRAB

LEASE SALE AREAS IN THE SOUTHEAST BERING SEA





A = SURFACE OIL TRAJECTORIES DURING SUMMER.

B = SURFACE OIL TRAJECTORIES DURING W INTER.

(BOTH FROM LEENDERTSE AND LIU 1981)

BRISTOL BAY
RED KING CRAB

SURFACE OIL TRAJECTORIES
IN THE SOUTHEAST BERING SEA

FEBRUARY 1984 | FIGURE 4.S-2

Other categories such as mature males and subadult juveniles have been adequately discussed in other reviews (Armstrong, et al. 1983b; Hayes 1983).

Sexually Mature Females

The relationship of sexually mature female crab to annual reproductive success and year class strength takes several forms in this analysis. First, it is assumed that some sort of spawner-recruit relationship does exist (e.g., Reeves and Marasco 1980) and that natural female abundance could decline to a point where extraneous perturbations such as oil would significantly exacerbate already low production of larvae. Second, the geographic location of spawning female stocks is of great significance to survival of young-of-the-year juveniles because water conditions in different areas may result in differential survival of larvae. Third, the origin of hatch partially determines the locations of megalopae at the time of metamorphosis and settlement to the benthos; the type of benthic material onto which juveniles settle is critical for initial survival.

Direct Effects on Adults. Oil effects on aquatic organisms may be manifested in several ways (Curl and Manen 1982): 1) rapid mortality resulting from acute exposures to high doses via external contact, inhalation and asphyxiation, or assimilation of hydrocarbon compounds that become toxic at a cellular and biochemical level; 2) bioaccumulation of sublethal amounts that may cause a decline in general vigor and are likely be lethal to the organisms (evidenced in reduced growth, susceptibility to disease, inhibition of feeding); 3) impaired reproduction, reduced broods and viability of progeny; 4) carcinogenic and mutagenic causes of tumors and morphological abnormalities; and 5) uptake of hydrocarbons causing tainting of commercial crab sold as food.

Overt, rapid mortality of adult crabs, including mature females, could be caused by exposure to rather high levels of hydrocarbons (notably the WSF) dissolved in water and via uptake into tissues and accumulation in certain organs. As a second mode of toxicity, water insoluble hydrocarbons mixed to the bottom and covering the benthos could kill crabs by actual coverage of the body and mechanical impairment of respiration and feeding. Toxic levels of WSF have not been well established for adult king crab, although it is known that adult stages are much less sensitive than are larvae and juveniles (Rice, et al. 1979; 1983; Armstrong, et al. 1983a). An approximate range of 96 hr LC_{50} values for adult crab is 4 to 8 mg WSF l^{-1} (Rice, et al. 1979). This is a rather high water concentration and may be found only in the immediate vicinity of a spill. Models of oil transport invariably account for rapid volitalization of a large fraction of the hydrocarbons and dilution of the remaining WSF, so that resultant concentrations are less than 1.0 mg l^{-1} only a few kilometers from a point source (Armstrong, et al. 1983b; Curl and Manen 1982). Since adult crabs are epibenthic, it seems unlikely that sufficiently high levels of oil WSF would affect a large area. Given the distribution of mature females in the' SEBS that exceeds an area of 50,000 km2, it seems unlikely that a majority of the adult populations would be significantly impacted via acute toxicity of the WSF.

Mixing and vertical transport of oil to the benthos might pose an alternative route of exposure of adult females to hydrocarbons. Whether or not a significant portion of the population would be acutely stressed is, again, related to the area affected. Transport models of Sonntag, et al. (1980) and an analysis by Curl and Manen (1982) predict that 5-16 g oil m^{-2} could reach the bottom. The toxicity of this to adults is difficult to gauge, but Armstrong, et al. (1983b) suggested that, over long exposures of several months, such levels would likely impact developing eggs more than adults (see <u>Effects on Reproduction</u>). Since most scenarios for the SEBS have dealt with small spills (e.g., 10,000 bbl spilled off the NAS covered an area of about 8 x 20 km), adult populations are probably well protected from benthic pollution by virtue of the vast size of the species range.

Ecological Vulnerability of Females. One proviso must be integrated into the topic of acute toxicity. The NAS lease sale area lies adjacent to the coastal domain of the Izembek Lagoon and Port Moller. Spills in this area could be driven by nearshore currents (Leendertse and Liu 1981) and transported northeast into shallow water. A very large spill (in excess of 500,000 bbl) could cover a significant portion of the coastal domain and, in this turbulent, well mixed system, reach the benthos in unknown concentrations. As shown for past years, a large fraction of the mature female population sometimes occurs nearshore and, thus, could be vulnerable to acute oil toxicity. If the event occurred prior to peak egg hatch in early May, then loss of those females and any resultant impact on the population would be exacerbated by loss of a portion of the annual reproductive effort. Redistribution of mature females around the SEBS on an annual basis would change the relative vulnerability of the population as far as exposure in shallow, nearshore water. Data presented in this report show a shift away from the coastline in 1983 compared to distribution in 1979/80, for example, and so the spatial vulnerability of mature females relative to nearshore spills would probably be reduced as a consequence.

Effects on Reproduction. The effects of oil need not be manifested in overt mortality to impact the adults and, in turn, younger stages of the species. Sublethal toxicity might perturb the population through a combination of physiological and behavioral processes that regulate reproduction. Oil in water and/or sediments could affect reproduction in several ways: 1) Sediment and infaunal concentrations of hydrocarbons become so high that feeding of crabs is curtailed either by loss of prey (clams, polychaetes, other crustaceans)and/or anorexia. Thus, energetic requirements are not met and gamete production is reduced or inhibited. 2) Hydrocarbons are absorbed and/or ingested with food and deposited in eggs and sperm. At critically high (but as yet unknown) concentrations, viability of the gametes is impaired and normal development of embryos is arrested, resulting in greatly reduced hatching success. 3) Normal gametes are produced and eggs fertilized and extruded, but sediment hydrocarbons are absorbed directly by the lipid-rich developing embryo and remaining yolk mass. Again, at critically high tissue levels (unknown), development is arrested and the year-class weakened by virtue of poor hatch (see Toxicity to Eggs). 4) Oil WSF adversely affects chemosensory cues used for mating after the females molt, so that copulation is reduced.

The first hypothesis is predicated on the possibility that extensive mortality of epibenthic and infaunal prey would severely restrict feeding by crabs. Scenarios of oil transport to the benthos (summarized by Curl and Manen 1982) predict accumulation of amounts up to 60 g m^{-2} and resultant high mortality. Sonntag et al. (1980) predicted that annual benthic productivity ("benthic food growth rate") would reach zero at sediment oil concentrations of 8 to 16 g oil m^{-2}, well within the range of possible sediment concentrations predicted by participants of the 1981 Anchorage Workshop. In the very large spill scenario of about 500,000 bbl of oil, several thousand square kilometers could be so impacted and food resources of crabs reduced on a large scale. In addition to outright loss of prey, food consumption could be reduced by a sublethal, anorexic response to increasing tissue levels of oil as shown for lobster larvae (Wells and Sprague 1976).

Reduction of food intake by either cause could trigger an energetic imbalance in which metabolic needs account for the largest expenditure of ingested energy and little remains for tissue and gamete production (Edwards 1978). Sub-optimal temperatures might exacerbate the effect of oil on growth and energy budgets of a species as theorized by Warren (1971). Sublethal oil concentrations can act synergistically with sub-optimal temperatures to reduce energy consumption (Edwards 1978), but at the same time increase respiration even at cold temperatures (Laughlin and Neff 1977), thereby further narrowing the scope of growth.

The second hypothesized effect of oil on reproduction is caused by transfer of hydrocarbons ingested and absorbed by adults to gametes. Rapid uptake of petroleum hydrocarbons has been demonstrated in several species of crustaceans (Anderson 1975; Cox, et al. 1976; Tatem 1977). While both adult and larval stages are capable of rapid elimination of hydrocarbons accumulated via the diet, metabolic products appear to be resistant to deputation (Corner, et al. 1976; Lee, et al. 1976; Sanborn and Malins 1977). Residues amounting to 10 percent of the initial level were found in adult copepods which had been exposed for 24 hours (Harris, et al . 1977). Neff, et al . (cited by Varanasi and Mal ins 1977) found rapid accumulation of naphthalene derivatives by penaeid shrimp that reached tissue levels 100 times greater than those in the exposure water. Highest and most persistent residues were found in the hepatopancreas that directly supplies nutrient materials to the gonads for gametogenesis.

Transfer of naphthalene to eggs was found to occur in the marine polychaete Neanthes arenaceodentata (Rossi and Anderson 1977). Bl ue crab (Cal 1 inectes sapidus) ingesting radiolabeled hydrocarbons assimilated 2 to 10 percent and stored up to 50 percent of this amount in the hepatopancreas, which was the only organ assayed that still contained radioactivity after 25 days of deputation (Lee, et al. 1976). Again, a direct translocation to and biomagnification of hydrocarbons in lipid-rich gametes is possible, although not well studied. Sufficiently high hydrocarbon levels in egg yolk and developing embryos could cause abnormal development.

A final sublethal stress encountered by mature females exposed to oil which could impair copulation and result in a high proportion of infertile egg masses is that related to chemoreception. As previously described, a sexually mature male locates and embraces a female just prior to her molt and they copulate immediately thereafter. Failure to copulate within five days post-ecdysis results in infertile egg masses. Location of a female partner is based on strong pheromone cues that are detected by chemosensory organs. Pearson, et al. (1980) demonstrated that Dungeness crab can detect hydrocarbons at a level of a few ug l^{-1}. Following an oil spill, water concentrations may exceed 100-200 ug l^{-1} (Hood and Calder 1981), and might impair chemosensory location of females or otherwise alter behavior to reduce breeding within the population.

Developing Eggs

Although larvae are pelagic, the eggs from which they hatch and their prior embryonic development occurs in the benthos and spans up to 11 months for red king crab. Uptake of hydrocarbons by eggs directly from bottom or interstitial water may adversely affect development of embryos. No studies of direct hydrocarbon uptake by crab or shrimp eggs and embryos are available, but transfer of naphthalenes to brooding eggs (high in lipids) was reported to occur in the marine polychaete Neanthes arenaceodentata (Rossi and Anderson 1977), while absorption from sea water occurred (independent of adults) in eggs of the Pacific herring (Eldridge, et al. 1978). The lethal effect such exposure can have on developing embryos was shown by Tatem (1977) who subjected gravid female shrimps (Palaemonetes pugio) to 1.44 mg l^{-1} WSF for 72 hours. One week later control females released an average of 45 larvae each while those exposed to oil released only nine each. Further studies of oil toxicity to developing eggs is warranted in light of possible oil impact to red and blue king crabs that reproduce in relatively shallow, near-shore areas. Since oil degrades slowly in the sediments of very cold arctic waters (Butler and Levy 1978; Curl and Manen 1982; Mayo, et al. 1978), and since female king crabs brood eggs for 11 months, protracted exposure of eggs to hydrocarbons can result from oil spills that reach reproductive grounds.

In oil spill scenarios discussed at North Aleutian Shelf synthesis meeting (Thornsteinson, in press) and in previous discussions in this section, the greatest threat from oil to developing eggs comes in the nearshore area of the coastal domain, particularly if the annual proportion of spawning females is high i n that region. Whether females that hatch eggs within the coastal domain in spring are present there throughout egg maturation is unknown. It can be argued that a nearshore location has the advantage of warmer bottom water as a stimulus to faster development than found in the middle domain. It may directly benefit the female to feed nearshore through the summer and fall if food and temperatures are more conducive to faster growth and ovarian development for the next annual egg mass. If these females do not undergo annual onshore/offshore migrations, then year-round residence in the shallow coastal domain following a large spill could result in a chronic exposure to eggs to hydrocarbons.

Pelagic Larvae

This life history stanza is considered by many to be the most susceptible to oil pollution (Armstrong, et al. 1981b, 1983a,b; Curl and Manen 1982; Rice, et al . 1983). Such high vulnerability may reflect several relationships of larvae to oil that are unique compared to benthic stages. First, larvae are pelagic and as such, are situated in the water column close to spilled oil on the water surface. Second, they have a high frequency of molting which is a physiologically stressful process during which they are more susceptible to pollutant toxicity (Armstrong, et al . 1976). Third, they have a high surface area to volume ratio which may result in faster rates of uptake than occur in larger stages. Further, as developing larvae, they may not have the biochemical/cellular protection such as mixed function oxidases found in larger animals (Malins 1977a,b).

Oil Toxicity. A wealth of information on oil toxicity to marine invertebrates has been made widely available (Malins 1977a; Wolfe 1977). Many investigators have been specifically concerned with sensitivity of larval crustaceans (Bigford 1977; Caldwell, et al. 1977; Cucci and Epifanio 1979; Tatem 1977; Wells and Sprague 1976). Karinen (1981) and Rice, et al . (1983) have reviewed toxicity of oil to Pacific Northwest and Alaskan species of shrimp and crab including Dungeness crab, king and Tanner crab, and pandalid shrimp. Rice, et al . (1976) and Vanderhorst, et al. (1976) reported that 96 hr LC_{50} values for juvenile and adult pandalid shrimp range from 0.8-11.0 mg l^{-1} WSF. Pandalid larvae, however, are a more sensitive life history stage as evidenced by 96 hr LC_{50} values from 1.0 mg l^{-1} WSF down to 0.3 mg l^{-1} for single aromatic compounds such as naphthalene (Mecklenburg, et al. 1977; Rice, et al. 1976, 1979). Sublethal effects including failure to swim and/or molt inhibition occurred at concentrations from 0.7 to 0.3 mg l^{-1} WSF. A 96 hr exposure of pandalid larvae to 0.6 mg l^{-1} WSF caused a 70 percent reduction in molting from S1 to S11 (Mecklenburg, et al. 1977). Dungeness crab zoeae were susceptible to WSF as low as 0.22 mg l^{-1} (Caldwell, et al. 1977). Larval king and Tanner crab are equally sensitive to hydrocarbons. Death of Paralithodes camtschatica larvae or failure to swim was caused by WSF of 0.8 to 2.0 mg l^{-1} (Brodersen, et al . 1977; Mecklenburg, et al. 1977}, and Chionoecetes bairdi larvae were immobilized by a 96 hr exposure to 1.7 mg l^{-1} WSF (Brodersen, et al. 1977).

Studies with other larval decapods indicate that toxic oil concentrations may be even lower than those discussed above when based on assays of single hydrocarbons, exposures longer than 96 hr, or based on sensitive sublethal criteria. Larval lobster (Homarus americanus) ceased feeding at 0.19 mg l^{-1} WSF and had a 30-day LC_{50} value of 0.14 mg l^{-1} (Wells and Sprague 1976). Specific compounds such as naphthalene are very toxic and caused narcotization followed by death of pandalid shrimp and crab larvae at concentrations of 8-12 ug l^{-1} during exposures of less than 24 hr (Sanborn and Malins 1977). Toxic oil concentrations range as low as 0.15 mg l^{-1} WSF and may be somewhat lower for specific compounds. Moore and Dwyer (1974) give a sublethal range of 0.0011-0.1 mg l^{-1} WSF as stressful to larvae. Wells and Sprague (1976) suggest a multiplier of 0.03 should be applied to LC_{50} concentrations to establish "safe" levels; this would result in acceptable concentrations less than 1 ug l^{-1}. Armstrong, et al. (1983b) suggest that the toxic threshold value of 0.2 mg l^{-1} WSF used in oil spill scenarios be lowered to 0.05 to 0.1 mg l^{-1} in light of this evidence.

Ecological Vulnerability. Armstrong, et al. (1983b) discussed in detail the types and magnitudes of stress that could affect larvae, and also the spatial and temporal vulnerability of this stage. They criticized some assumptions about larval biology used in previous models to predict oil impact (e.g., Sonntag, et al . 1980), and updated biological information obtained through 1983 in order to better portray possible oil stress. Information on larvae obtained during the present study helps to substantiate conclusions made by Armstrong, et al. (1983b) and improves a sense of the relationship between larval settlement and young juvenile distribution nearshore. Yet, the relative importance of nearshore, coastal domain larvae is not so clear given the higher offshore densities found over Bristol Bay in June 1983.

This life history stanza still seems particularly susceptible to oil pollution given physiological, ecological and spatial characteristics of larvae. Data through 1982 indicate that a major portion of the larval population occurs along the 50 m isobath and probably is transported by long- shore currents to the northeast as hypothesized by Hebard (1959), Haynes (1974) and Armstrong, et al. (1983b). Although the frontal system depicted by Kinder and Schumacher (1981a) is not as well studied along the NAS as in upper Bristol Bay, its integrity might be such as to entrain subsurface oil at the front with resultant transport concurrent with larval crab. Cline, et al. (1981) concluded from methane profiles originating from Port Moller that material rarely penetrated more than 20 km offshore and was mostly entrained shoreward of the 50 m front while moving to the northeast, thus substantiating the notion of a strong front in this region. While movement of oil as a surface film by winds results in extensive coverage within brief time periods in the models of Leendertse and Liu (1981) and Pelto and Manen (1983), mixing of oil into the water column along the 50 m isobath might pose a more serious threat to red king crab larvae along the NAS for 10-20 days after a spill .

Larval distribution and abundance in April and June 1983 furnish new information on three points: 1) there is probably considerable interannual variability in abundance and distribution of larvae; 2) significant densities of larvae occur seaward of the inner front over the middle shelf domain between 50-70 m; 3) there is evidence that larvae may undergo a diel vertical migration but are-not abundant in the upper 10 m.

The scarcity of larvae in 1983 along the entire nearshore perimeter (<50 m) of Bristol Bay indicates that weak annual production can occur. Densities were 30-fold less between Izembek Lagoon and Cape Seviavin in 1983 than in 1982, a reduction that mirrors NMFS estimates of substantially fewer mature females at the same time. Whether or not the strength of the 1983 benthic juvenile year class is correspondingly weak will not be known for several years. Nonetheless, larvae surviving through the megalope stage metamorphosed to benthic instars at several locations inside 50 m along the NAS, and they were caught in September 1983 (see Figure 3.5-6). This fact further substantiates the importance of nearshore coastal waters to larval production and survival, perhaps even more so in a year of low hatch. A major oil spill in or adjacent to the nearshore coastal domain would significantly threaten a larval year class if, as in 1983, natural production were already low, and oil pollution were to compound zoeal mortality that is probably already high via natural processes. The greatest concern in this equation of larval production versus young-of-the-year juvenile strength, is the magnitude and location of megalope at metamorphosis.

Occurrence of larvae over central Bristol Bay at intermediate densities (relative to nearshore abundance in 1982) between 50 m and 70 m (Figures 3.2-2 and 4.1-1) may confirm earlier observations (Armstrong, et al. 1983b; Haynes 1974) that production occurs in this area. The link between offshore larval cohorts and young-of-the-year nearshore juveniles is still not clear. As previously stated, based on models of prevailing currents and trajectories of transport, larvae from this area would not likely reach nearshore locations along the NAS. If the offshore larvae develop in place and settle to the benthos of central

Bristol Bay, resultant mortality is likely to be so high that the cohort contributes little to the juvenile year class. From this line of thinking, it can be argued that oil pollution and mortality of larvae in the 50-70 m central Bristol Bay region is of little consequence. From a contrary perspective, the offshore cohort could be a vital source of juveniles that settle to Kvichak Bay. Numbers of juveniles and repeating year classes in this area suggest that the far eastern end of Bristol Bay is significant to juvenile recruitment (this point should be given a high priority in future work).

Armstrong, et al. (1983b) criticized models of oil impact on decapod larvae (Curl and Manen 1982; Sonntag, et al. 1980) that mixed oil to a depth of 50 m and argued that larvae would invariably move near (or away from) the surface over a period of several days. Data from the present study suggest such vertical movement might be a regular daily event. The point relative to oil impacts is that a given volume of oil could be more toxic to a population near the surface if spread rapidly in a horizontal plane and mixed to a depth of, say 20 m. Behavior of the larvae would repeatedly bring them in contact with this layer containing higher pollutant concentrations.

A further ecological consideration raised by Armstrong, et al. (1983b) is whether hatching is synchronized along the NAS and, in turn, whether one or several cohorts are produced annually. They criticized earlier assumptions about timing of hatch used by Sonntag, et al. (1980) to model oil impact at the critical point of the larval stanza. Rather than a protracted hatch over the three months of April, May and June (20%, 60% and 20% per month of yearly total), data from 1982 and 1983 indicate that, within a wide geographic area (e.g., Unimak Island to Cape Seniavin), the larval year class is hatched over a short period of 2-3 weeks. Since hatching seems to be a well-synchronized event, a major oil spill that affects a significant proportion of a larval year-class would not be mitigated by a later hatch of larvae after oil disperses below toxic levels. For example, first stage king crab zoeae that are killed by oil north of Unimak Island in late April could not be replaced by other first stage zoeae hatched later in the same area (although they may be replaced by larvae also hatched in April and subsequently transported to the affected area).

An exception to this statement, is the observation that offshore larvae in the 50-70 m central Bristol Bay area were a cohort which may have hatched about three weeks later than those nearshore. Again, it is not known if this population adds to nearshore juvenile recruitment and in so doing, could mitigate the loss of nearshore larvae to oil pollution.

Young Juveniles

An important but poorly studied life history stanza in the southeastern Bering Sea is newly settled juveniles up to two years old. Their susceptibility to oil pollution may be very high, in part, because of highly restricted distribution in critical but scarce habitat. Very young juvenile king crabs (less than two years old) in the Kodiak region prefer rocky, cobble habitat that affords shelter from predators (Feder 1978; , Jewett and Powel 1 1981). Very little habitat of this type exists along the NAS (Michel, et al. 1982) and young-of-the-year (0+) juveniles that settle on open bottom are probably vulnerable to heavy predation. Thus, any habitat that offers protection to young crabs is critical to benthic survival. During an intensive search for 0+ and 1+ juvenile king crabs along the NAS in June, August and October 1982, the only specimens of this size/age category were taken around Amak Island off Izembek Lagoon (W. Pearson, Battelle Northwest, pers. comm.)

It was the apparent scarcity of 0+ and 1+ juveniles during the 1982 cruises that led OCSEAP to fund this more systematic and broadscale survey in 1983. During all three cruises conducted during the present study, juveniles were patchily distributed and were associated with rather specific substrates that apparently afford shelter (Section 3.4). Areas off Port Moller, Cape Seniavin, Port Heiden, and in Kvichak and

Togiak Bays where young juveniles were caught, are all in water less than 50 m. The centers of juvenile abundance are fairly far to the northeast of the NAS lease sale area and beyond the predicted reach of oil pollution in scenarios of the NAS synthesis workshop (Armstrong, et al. 1983a). However, the paucity of young juveniles between Unimak Island and Port Moller may reflect the shift of females away from this area and, thus, reduced larval hatch compared to historic levels.

The question of spatial vulnerability of young juveniles is difficult to gauge without a sense of final lease sale sites and how close to important juvenile centers oil development might be located. A more meaningful analysis of this question should simultaneously consider habitat requirements of the juveniles. Based on 1983 data, the following conclusions can be drawn: 1) O+ to 1+ juveniles are most abundant in water less than 50 m within the coastal domain; 2) they are most common on a substrate that offers refuge from predators as well as food (e.g., small cobble, shell hash, living biological material); 3) not all areas have the same number of co-existing juvenile year classes which suggests that the extent of annual larval dispersal and subsequent juvenile settlement is variable; 4) there are areas of relatively high juvenile abundance in eastern and northern Bristol Bay where no larvae were found in 1983, and 5) the relationships of such settlement areas to larval production and transport is unknown.

Given the apparently patchy and limited habitat of young juveniles, its location in the mainstream of nearshore currents, and shallow depths, it seems possible that oil from a large spill could reach juvenile locations around Port Moller and Cape Seniavin and be mixed to the bottom; whether toxicity would ensue is arguable. Heavy oiling of the benthos to the extent discussed by Curl and Manen (1982) and Sonntag, et al. (1980), at about 8-16 g m^{-2}, could be acutely toxic as a coating or as high WSF concentration at the sediment surface. Such heavy benthic contamination would be limited to a much smaller area than covered by surface oil, and likely would not affect a significant portion of the entire NAS or Bristol Bay juvenile population.

Long-term, sublethal effects may also not pose a great threat except in the immediate vicinity of a spill. Experiments conducted in 1982-1983 at the Auke Bay NMFS lab studied the survival and growth of young juvenile king crab fed oiled food (mussels) or kept on oiled sediment. In neither experiment did juveniles seem to be adversely affected based on preliminary analysis of data (J. Garrett, S.D. Rice, C. Broderson, NMFS Auke Bay Lab, pers. communication). In another experiment designed to study sublethal effects of oil in water (WSF) to crab, energetic criteria were used to compare relative scopes for growth (Warren 1971) between treatments. At high but sublethal WSF concentrations, juvenile crab had reduced feeding rates and therefore consumed less (T. Shirley, Univ. Alaska Juneau, pers. communication). This situation, if prolonged, would inhibit growth and survival, but the former results indicate that juvenile crab may be fairly resistant to oil exposure via food and sediments.

Although longevity of oil in sediments is great, it is not known whether there is a constant leaching of the WSF in toxic quantities into overlying water. Given a tremendous capacity by the system to dilute toxicants emanating from a point-source, it seems unlikely that oil at toxic levels would chronically affect a benthic community much beyond the confines of the immediate polluted area. An estimate of adverse effect might be reduced to a calculation of the proportion of habitat polluted relative to the total occupied by the species during any life-history stanza.

SECTION 5.0

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APPENDIX A:

MEAN LARVAL RED KING CRAB DENSITIES BY STAGE, CRUISE AND SUBAREA

APPENDIX A

MEAN LARVAL RED KING CRAB DENSITIES BY STAGE, CRUISE AND SUBAREA (a)

	STAGE 1	STAGE 2	STAGE 3	STAGE 4	STAGE 5
CRUISE 83-1 (APRIL-MAY)					
IZEMBEK	0.81	0,00	0.00	0.00	0.00
PORT MOLLER	5.12	0*IO	0*00	0,00	0400
PORT HEIDEN	0.65	0*00	0*00	0.00	0*00
KVICHAK BAY	0.00	0.00	0,00	0.00	0.00
TOGIAK BAY	0.03	0400	0.00	0.00	0*00
OUTER BRISTOL BAY	O*39	0*00	0.00	0,00	0*00
CRUISE 83-2 (MAY)					
IZEMBEK	0.09	4.24	0*12	0*00	0,00
PORT MOLLER	6.85	50 .71	10.23	0.80	0*00
CRUISE 83-3 (JUNE)					
IZEMBEK	()*05	0.21	0.20	0411	0*00
PORT MOLLER	0.05	0.41	0.96	1.09	0.00
PORT HEIDEN	0*00	0.08	0.28	0.75	0*00
KVICHAK BAY	0*00	0.30	1.20	0413	0,00
TOGIAK BAY	0.52	0.74	0*7Q	0.17	0*00
OUTER BRISTOL BAY	0.19	2.12	13.26	11.74	0*00
CRUISE 83-5 (SEPTEMBER)					
IZEMBEK	0*00	0400	0*00	0.00	0.00
PORT MOLLER	0*00	0*00	0,00	0*00	0*00
PORT HEIDEN	0*00	0*00	0000	0*00	0,00
KVICHAK BAY	0,00	0.00	0400	0*00	0,00
TOGIAK BAY	0*00	0*00	0*00	0*00	0*00
OUTER BRISTOL BAY	0*00	0*00	0*00	0,00	0.00

(a) Means are geometric.

APPENDIX B:

TRAWL GEAR TYPES USED BY CRUISE AND STATION

APPENDIX B

TRAWL GEAR TYPES USED BY CRUISE AND STATION

	Cruise				Cruise		
Station	83-1	83-3	83-5	Station	83-1	83-3	83-5
BB190	T			PM360			
BB199	T2			PM370	T	T	T
BB250	T2			PM440		T	
BB270	T,R			PM540		R	
BB299	T2	T		PM620	R	T2	T
BB340	T			PM630		T	
BB370	R			PM650	R	T2	T
BB390	T			PM660			
BB440				PM670	T	T2	T
BB450	T	T		PM730	R2	T2	T4
BB480	T	T		PM735		R	
BB557	T	T		PM740		R2	
BB555		T		PM745		T,R	
BB560		T		PM750		R2	
BB665		T		PM820	R2	T	T
BB670		T		PM830	R	T	R
BB760	T	T,R	T	PM850	R	T	T
BB770	T	T	T	PM870			
IL130	T	T		PM920	T	T	T
IL150	T	T	T	PM930	R	T	T
IL160	T	T		PM950	R	T	T
IL220		R		PM970			
IL230		T	R	PM010			T3
IL260		R	T	PH120			T
IL270		T		PH130	R	T	T
IL320	T			PH150	T	T	T
IL330	T,R			PH220	R	T,R	R
IL350				PH230	R2	T,R	T
IL370	T,R			PH250	R	T,R	T
IL420	R	R3	R	PH320	T	T,R	T
IL430	R	R	R	PH330	T	T	
I L440	R	T	T	PH350	T	T,R	T
11470	R	T	T	TB130		T	
PM150		T		TB150	T	T	
PM320	T	T	T	TB216			T
PM330	T	T	T	TB220	R	T	
PM350	T5	T	T	TB230	R	T	

APPENDIX B

(continued)

Station	Cruise 83-1	Cruise 83-3	Cruise 83-5
TB250	T	T,R	T
TB329	T2	T,R2	T
TB320	R2	T2,R	T
TB330	T	T	T
TB350	T	T	T
TB429	R2	T	T
TB430	T	R	
TB431	R	T	T
TB450	R	T	T
TB520	T	T	
TB540	R	T	T
TB550	R2	T	
KB150	R	T	R
KB250	R	T	T
KB240	R	T	T
KB2*9	R	T	
KB2*8		R	T
KB2*7		R2	
KB2*6		R	
KB2*5		R	
KB2*4	R6	R	R7
KB2*3		R	
KB2*2		R8	
KB2*1			R
KB2*0	R	R	
KB330		R	
KB320	R	R	
Total	T-45 R-45	T-68 R-42	T-44 R-15
Stations:	T-38 R-35	T-63 R-29	T-39 R-9
Total	70	82	48

(a) Key: T = Trynet, 1 sample
R = Rockdredge, 1 sample

APPENDIX C:

TRAWL/DREDGE NOTES

APPENDIX C

TRAWL/DREDGE NOTES

Station	Haul Number	Remarks
Cruise 83-3 (June):		
BB299	01	Macoma sp. and whelk shell debris, parchment-like worm tubes. Hermit crabs in whelk shells. A C. bairdi female was infested with parasites under abdominal flap.
IL160	02	Sand dollars, sea stars, flatfish, shrimp, broken bivalves. Plenty of Cyanea.
IL150	03	Sand dollars, many Asterias amurensis, rock sole, yellowfin sole, some shell debris, fish bones. One P. camtschatica carapace, 115 mm wide by 108 mm long; clean bright shell. One large cod with very full gut; contents in advanced stage of digestion, mostly mysid or euphausiid; remains of one fish, possibly sandlance.
IL130	04	Large catch of sole, sculpins, with sand dollars, Asterias, clams. Very clean haul. Rock sole guts (4) and yellowfin sole guts contained small heart urchin tests and solitary ascidians (olive pit look-alikes). One yellow Irish lord examined for gut content: sandlance and euphausids.
IL220	05	Rock dredge contained black, coarse sand; bivalves (Astarte) and sand dollars very abundant. Drift algae and bryozoans also in haul. NOTE: the catch recorded represents the material retained in plastic fish baskets after washing; some of the very small bivalves were lost.
IL230	06	Trynet haul contained anabundance of sponge,bryozoans and gastropod shells, with associate nard-bottom fauna.
IL260	07	Rock dredge haul filled completely with gravel, fine to coarse. Bag was probably filled after first 4 minutes, as evidenced by dramatic change in wire angle. Haul included sea stars, some sand dollars, polychaetes, sandlance and hermit crabs.

APPENDIX C

(continued)

Station	Haul Number	Remarks
IL270	08	Trynet haul contained sponge (hermit crab sponge), small amount of shell debris. Both Tanner crab species, one hair crab, several flatfish species.
IL470	09	Trynet: starfish and flatfish abundant.
IL440	10	Same as Haul 09.
IL430	11	Cobble and gravel.
IL420	12	Rock dredge: barnacles (B. nubilus), jingles, gastropod shell.
	13	Rock dredge: black cobble-gravel.
	14	Same as Haul 12.
		(All of these three hauls had abundant hermit crabs, rock and other crabs.)
PM320	15	Color echo-sounder shows lots of targets in shallow (16-18 m), nearshore water. Trynet haul contained yellowfin and rock sole, pollock, cod, sculpins, sandfish, small halibut (6) and a few flathead sole. Many Asterias, some Crangonids and sea anemones.
PM330	16	Short trawl (2 min.) contained Asterias, yellowfin sole, rock sole, one longhead dab, one small halibut, some pollock and hermit crabs.
PM350	17	Trynet haul contained Asterias (62 lbs.), Evasterias (1), crangonids, pagurids and flathead sole.
PM370	18	Trynet haul contained Spisula clams and shell debris, small sand dollars, crangonids, yellowfin and rock sole, Levasterias, Asterias and Tanner crabs (opilio).
PM670	19	Trynet came aboard dripping with sea onions (Boltenia) from the footrope and chains, and a load of same in the bag. Also abundant were golden, leafy bryozoan. Levasterias and some Tanner and red king crabs (few). The usual compliment of yellowfin, rock sole and other flatfish were present.

APPENDIX C

(continued)

Station	Haul Number	Remarks
PM650	20	The trynet haul was dominated by Asterias, large brown anemones (30 lbs.), two red king crabs and the usual soles.
PM730	21	Trynet haul contained Asterias (185 lbs.), yellowfin and rock sole, few hermit crabs and one juvenile red king crab.
PM620	22	Yellowfin sole once again dominated the try net catch (100+ lbs.), with Asterias also abundant. Razor clams (7), hermit crabs and rock sole were few; one red king crab juvenile.
PM820	23	Trynet haul contained starry flounder, Asterias, mussels (being eaten by stars), rock sole and Argis (Crangonidae).
PM830	24	Trynet haul dominated by rock and yellowfin sole; a few starry flounder, Asterias, young Pacific cod and walleye pollock, and shell debris (Spisula).
PM850	25	Trynet haul contained Asterias, yellowfin sole, rock sole, Boltenia and a couple of longhead dab.
BB770	26	Very large haul. Trynet full of Boltenia (57.5 lbs.), sponge (61 lbs.), sand dollars {and epifaunal green slime), bryozoans, ascidea, red king crabs (3-4 year olds), and the usual yellowfin and rock sole.
PM950	27	Trynet contained a big skate, some large cod, stars, sea onions, and soles.
PM930	28	Trynet haul contained two juvenile red king crab, many sea onions (Boltenia), bryozoans, sea stars (38 lbs.), soles, lots of amphipods and one halibut.
PM920	29	Sea stars and flatfish once again dominated the trynet haul, with the appearance of juvenile yellowfin sole. A high diversity of fish species was noted by the scientific staff.

APPENDIX C

(continued)

Station	Haul Number	Remarks
PH130	30	A 7-minute trynet tow was dominated by sea stars and flat fish, mostly yellowfin sole and rock sole. Lower diversity than last haul.
PH150	31	No field notes.
PH220	32	Large and small yellowfin sole in this trynet haul; only small rock sole present. Small plaice and dab, sea stars, Crangon and threaded sculpin.
PH220	33	A rock dredge tow at the same station as Haul 32 came up with no substrate material, a few sea stars and some small flatfish. Must be a sand bottom (?).
PH230	34	Rock dredge haul came up with a bag one-third full of gravel. Fauna consisted of lots of Corophium amphipod tube clumps, erect bryozoans, Crossaster and Asterias, small decorator crabs very abundant, some hermit crabs. Two 6 mm red king crabs were found, one inside an empty Spisula shell, one in the gravel. Gravel was sluice sorted.
PH230	35	Trynet tow in the same area contained a diversity of organisms, including: Evasterias, a few Crossaster and Leptasterias. Corophium masses, tube worms, Balanus, yellowfin sole, small rock sole, numerous Sclerocrangon, numerous Oregonia, lots of Asterias, sponge, soft coral and others.
PH250	36	Trynet contained erect bryozoa, large Hyas lyratus, large holothuroidians, Asterias and some soles.
PH250	37	Rock dredge came up with coarse sand, Asterias, tellin clams, sea glob (Aplidium sp.), Sclerocrangon. Not a quantitative sample.
BB760	38	Rock dredge contained a very small volume of material. Boltenia ovifera, fine gravel and shell debris, basket stars, hermit crabs (P. ochotensis), and some small Hippolytid shrimp.

APPENDIX C

(continued)

Station	Haul Number	Remarks
BB760	39	No field notes.
BB665	40	Trynet: many Boltenia ovifera, Asterias; eight red king crabs (4-5 year olds), five Tanner crabs (bairdi and opilio), yellowfin and rock sole, longhead dabs and Crangon dalli.
TB550	41	Trynet haul with lots of sea onions (Boltenia ovifera), a load of large Asterias, a few small Asterias, one Tanner crab, 28 red king crabs (4-5 year olds), rock and yel lowfin sole.
KB250	42	No field notes.
PH370	43	Rock dredge: sand/gravel, broken shell, Asterias, some Boltenia, amphipods, hermit crabs and Crangon.
PH350	44	Trynet haul: lots of sponge, Boltenia (56 lbs.), Asterias (119 lbs.), Evasterias, a high diversity of decapod shrimp (10 spp.), lots of crabs (Oregonia, Hyas, Tellmessus), snails, hermits, bivalves, yellow-fin and rock sole.
PH330	45	A small catch in the trynet, many small Asterias, some rock and yellowfin sole.
PH320	46	Trynet: small catch of barnacles, yellowfin and rocksole, Asterias.
PH320	47	Rock dredge: gravel, sand and silt. Asterias and Crangon dalli.
KB150	48	Trynet, small catch. Yellowfin and rock sole.
KB240	49	No field data.
KB320	50	Trynet lost, doors and all.

Station	Haul Number	Remarks
KB320	51	Rock dredge haul full of gravel and rock sole. Lots of urchins, some Tellmessus, Asterias, Henricia, Crossaster, Sclerocrangon and Crangon.
KB2*9	52	Trynet haul contained several boulders (up to 150 lbs.), one red king crab (30-40 mm), Asterias (predominantly small stars 1 ess than 20 mm dia.) , threaded sculpin and many small flatfish (including three halibut).
KB2*O	53	Rock dredge contained cobble, gravel and a boulder mixed with coarse sand. Thousands of Eupentacta sp., a small cucumber, and hundreds of Pagurus beringanus. A few Crossaster, Henricia, Clinocardium and Frustula.
KB2*2	54	Rock dredge haul: rock (largest 12"X 10"X 6") and cobble (1 to 6"). Small Balanus on rocks, some Leptasterias polaris, Henricia, numerous Calliastoma, some urchins, sponge, Crangonids.
KB2*2	55	Rock dredge: small amount of 2-4" cobble with Sclero-crangon, P. beringanus, tube worms (sand) in small clumps.
KB2*2	56	Rock dredge haul: small catch; cobble. Some urchins, Calliostoma, Leptasterias, Neptunea ventricosa.
KB2*2	57	Rock dredge: 2-6" rock with Balanus, pebble tube worm, seven red king crab (10-40 mm), Crossaster, Henricia, Leptasterias, Pagurus beringanus, 1 obed ascidian, brightbelly sculpin.
KB2*2	59	Two red king crab. Similar to Haul 57, sponge and Margaritas snail.
KB2*2	60	Rock dredge, rocky as previous hauls, no red king crabs, tube worms, several urchins.
KB2*2	61	Rock dredge, gravel to 2" rock. Five red king crabs, more barnacles than before (a subjective estimate), hermit crabs, some stars, very few tube worms. Generally less small grained material. One large clump of tundra grass, decomposing. Brightbelly sculpin, small clams.

Station	Haul Number	Remarks
KB2*4	62	Rock dredge, small (l-2") to large (10-15") rock. Very abundant tubiculous polychaetes, two red king crabs, urchins, Sclerocrangon, Crossaster, Henricia, threaded sculpin, gastropod and hermits.
KB2*3	63	Rock dredge: gravel to small stones, a few rocks. Abundant Mytilus binding stones together. One Asterias and one Evasterias, hermits, crangonids, a few urchins, small sponge, cockle, some erect bryozoans, moon snail (Natica clausa) and egg masses.
KB2*5	64	Rock dredge. Gravel and stone, abundant mussels, larger individuals than at KB2*3, some stars, hermits and crangonids.
KB2*6	65	Rock dredge. Eight red king crabs *in* rock up to 2", with some larger rock. Urchins, Crossaster, Levasterias, tube worm masses, large barnacles, Hyas, Sclerocrangon, gunnel.
KB2*7	66	Rock dredge, 1-3" rocks with gravel and coarse sand. No king crabs; urchins and hermits were dominante, with Asterias, Crossaster, Leptasterias, Margarites, few Hyas, tube worms and Sclerocrangon.
KB2*7	67	Rock dredge: coarse sand and gravel with large rocks (2-8") . Urchins and tube worms abundant, with usual rock 'fauna, as above, present. No king crabs.
KB2*8	68	Rock dredge: medium to coarse sand and gravel , some large rocks to 8". No king crabs. Usual rock fauna.
KB330	69	No field notes.
TB450	70	No field notes.
TB430	72	Trynet: small haul, mainly yellowfin sole.
TB429	73	Trynet: large catch, 300 lbs. of yellowfin sole, some Asterias and some P. ochotensis.

Station	Haul Number	Remarks
TB329	74	Trynet: another very large catch, this one dominated by bumpy shrimp, pricklebacks, crangonids, some yellowfin sole, threaded sculpins, small pollock, many large barnacle shells.
TB329	75	Rock dredge: silty-clay-sandy-gravel . Very little biota, some Asterias, a few anemones, crangonids. No fish.
TB329	76	Rock dredge: same as Haul 73, sample dumped.
TB320	78	Rock dredge contained fine to coarse sand, gravel and small roe-k. Pagurus beringanus, Crangon, Asterias, amphipods, cumaceans. All animals were small and very few in number (1-6).
TB320	79	Trynet haul contained yellowfin sole, rock sole, capelin, Crangon and hexagrammids.
TB320	80	No field notes.
TB330	81	No field notes.
TB450	82	Trynet haul contained Hyas coarctatus, three red king crabs, a large cod, yellowfin sole, longhead dabs, Pandalus goniurus, Crangon dalli and Boltenia.
TB350	83	Trynet haul contained lots of yellowfin sole, some rock sole (many small), seven red king crabs, lots of finger sponge, flathead sole (one large, rest small) and large plaice.
BB557	84	Trynet haul contained 23 red king crab (>60 mm), many Boltenia and an assemblage of yellowfin sole and Asterias. One large male Tanner crab.
TB250	85	Trynet haul contained predominantly yellowfin sole, rock sole, Asterias, a few pollock and sculpins, yellow sponge debris, Pacific cod and a few Crangonids.

APPENDIX C

(continued)

Station	Haul Number	Remarks
TB250	86	The rock dredge at this station collected very little. Shell debris was the predominant substrate. Animals included Asterias, yellow sponge, bivalves, amphipods, small sand dollars, many very tiny gastropod shells with hermit crabs in residence, some gastropod, some crangonids, two Neptunea heros and some black gravel.
TB230	87	Trynet haul contained a medium-sized catch of shell debris with attached red sea anemones, and sipunculids, rock and yellowfin sole, Asterias, and smaller numbers of plaice, dabs, pollock, cod, sculpins and poachers.
TB220	88	No field notes.
TB130	89	Trynet haul off Cape Newenham on a mud bottom yielded lots of Crangon dalli and Pandalus goniurus. Many capelin were caught, the majority of these were in very bad condition and partly eaten (many breeding males were in the catch: do they die after spawning and become food for the shrimp?). Yellowfin sole and small pollock and cod were present.
TB150	90	Trynet haul contained small yellowfin sole and rock sole, dabs, threaded sculpin.
BB450	91	Trynet haul contained large yellowfin sole, large pollock, one bearing female red king crab.
BB555	92	Trynet haul was fairly small, dominated by juvenile rock and yellowfin sole, three C. bairdi, one red king crab, and some crangonids. A few sand dollars, Asterias, pollock, dabs and flathead sole were present.
BB670	93	No field notes.
BB560	94	No field notes.

Station	Haul Number	Remarks
- - - -	- - - -	THE REMAINING HAULS WERE QUALITATIVE ONLY - - - - - - -
PM670	95	Trynet haul contained one Tanner crab (C. bairdi), many Boltenia ovifera and yellowfin sole. A few rock soles and P. ochotensis were present. Also, a few sand dollars and small poachers, sponge and one Leptasterias.
PM650	96	Trynet haul contained Evasterias, yellowfin and rock sole, lots of anemones, some poachers, one large plain sculpin, small cod, Crangon dalli, a large skate, one female red king crab, and pollock.
PM740	97	Rock dredge haul contained shell debris, lots of small bivalves, gastropod, Pagurus ochotensis, yellowfin sole and C. dalli.
PM740	98	Rock dredge haul contained items similar to Haul 92 with shell debris, small sand dollars, cockles, very little to no organic debris, no bryozoans. The sand dollars appeared very clean with no green algae. The shell debris was mainly Tellin shell.
PM735	99	Rock dredge haul filled with coarse sand/fine gravel. One red king crab (6 inn), quite a few hermit crabs, Elassochirus tennuamanis, and about 10 Asterias.
PM630	100	Trynet haul with flatfish, Asterias. Many juvenile rock sole.
PM730	101	Trynet haul contained the ususal yellowfin and rock sole, Asterias and one red king crab.
PM620	102	No field notes.
PM750	103	Rock dredge contained Asterias, Pagurus ochotensis, P. stevensae, Cyclocardia sp. (rough cockle), Crangon dalli, Margaritas (gastropod), sand dollars and shell debris. (This haul was with a 4:1 scope and at 1+ to 2 knots.)

APPENDIX C

(continued)

Station	Haul Number	Remarks
PM750	104	Rock dredge contained Asterias, one Lethasterias nanimensis and very little else, no debris. (This haul was with a 5:1 scope at 1 knot.)
PM745	105	Rock dredge contained very little: some shells, bivalves, Asterias.
PM745	106	Trynet: no catch, not on bottom.
PM540	107	Rock dredge contained fine sand and shell debris, small bivalves and gastropod. (This haul was in a small canyon heading toward the mouth of Port Moller.)
PM440	108	Trynet contained yellowfin and rock sole, including 50 mm rock sole, Asterias, Myoxocephalus jack, others.
PM250	109	Trynet haul contained flatfish, cod, Asterias, with halibut, starry skate, small pollock, sandlance, poachers, Pagurus ochotensis, crangonids. Rock sole were predominant.
PM150	110	Trynet haul contained lots of Asterias with urchins, rock and yellowfin sole and crangonids. Common in the haul were: Sclerocrangon, pollock, Pacific cod, ribbed sculpin, Oregonia gracilis, poachers, a few Lethasterias, Evasterius, anemones, bivalves and shells, Hyas lyratus and some pagurids. Many, many small Asterias were present.
BB480	111	No field notes.
		MonArk Trynet Stations. Port Moller
1		1244-1249 hours, 3:1 scope, 7 fathoms. Yellowfin sole, Asterias, Crangon dalli, one halibut, sand dollars, small dabs and rock sole.
2		1259-1309 hours, 3:1 scope, 6 fathoms. Yellowfin sole, sea stars, sand dollars, sand lance, poachers, rock sole, crangonids, three halibut.

APPENDIX C

(continued)

Station	Haul Number	Remarks
3		1328-1338 hours, 3:1 scope, 5 fathoms. Yellowfin sole, C. dalli, sandlance, sand dollars, rock sole, halibut, cod, plaice, dabs.
4		1353-1403 hours, 3:1 scope, 4 to 3 fathoms. Many small flatfish, same as #3, no halibut.
5		1408-1418 hours, 5:1 scope, 2 fathoms. Many small plaice, yellowfin sole, dabs, some rock sole, cod, Bering poacher, sandlances, sturgeon poacher, some algae.
6		1422-1432 hours, 4:1 scope, 5 fathoms. Similar to #5, with five small halibut.
7		1440-1450 hours, 3:1 scope, 5 fathoms. Two small halibut, large rock sole, yellowfin sole, C. dalli, sand dollars, dabs, plaice.
8		1515-1523 hours, 3:1 scope, 7 fathoms. One starry flounder, one halibut, yellowfin and rock sole, Asterias, sand dollars, plaice, dabs, sea weed.

Station	Haul Number	Remarks
Cruise 83-5 (September):		
IL150	01	Trynet. No substrate retrieved. Small catch of Asterias amurensis and rock sole.
IL260	02	Trynet. No substrate. Asterias, rock sole, yellowfin sole, a few hair and Tanner crab.
IL230	03	Rock dredge. Shell fragments, barnacle covered rocks, many small sea stars and crabs.
IL470	04	Trynet. No substrate. Star fish and flatfish.
IL440	05	Trynet. Total catch rock sole and Asterias.
IL430	06	Rock dredge. Shell fragments and a few large rocks. Brittlestars.
IL420	07	Rock dredge. Shell fragments, jingle shells, some pea gravel. Sponges.
IL320	08	Trynet. Some large rocks, mud, yellowfin sole and Asterias.
IL330	09	Trynet. No substrate. Flatfish and sea stars.
IL350	10	Trynet. Same as above.
IL370	11	Trynet. Large amount of clam shell debris. Flatfish, large sea stars, a few red king and Tanner crabs.
PM670	12	Trynet. No substrate. Flatfish, some sea stars, Boltenia ovifera.
PM650	13	Trynet. No substrate. Mostly flatfish and sea stars.
PM620	14	Trynet. Same as above.
PM730	15	Trynet. Some mud. Flatfish and sea stars.

APPENDIX C

(continued)

Station	Haul Number	Remarks
PM850	16	Trynet. No substrate. Boltenia, kelp fragments, flatfish and sea stars.
PM830	17	Rock dredge. Small black gravel, mussels.
PM820	18	Trynet. Rocks. Small catch of flatfish, cod and small sea stars.
PM930	19	Trynet. Flatfish and sea stars.
PM920	20	Trynet. Same as above.
PM950	21	Trynet. Flatfish and sea stars.
PM150	22	Trynet. Shell debris. Flatfish and sea stars.
PM130	23	Trynet. Sand. Clams, flatfish, sea stars.
PM230	24	Trynet. Small stones. Red tree coral, tube worms, red king crab (small) found in bryozoans, flatfish, sea stars.
PH250	25	Trynet. No substrate. Red tree coral, decorator crab, flatfish, sea stars.
PH350	26	Trynet. No substrate. Boltenia, bryozoans, flatfish, a few sea stars.
PH120	27	Trynet. Flatfish, a few sea stars, bryozoans.
PH220	28	Rock dredge. No substrate.
PH320	29	Trynet. Sand. Small numbers of flatfish and sea stars.
KB150	30	Rock dredge. Shell, gravel. Flatfish, sea stars.
KB250	31	Trynet. Boltenia, bryozoa, flatfish and sea stars.
TB450	32	Trynet. Flatfish and sea stars.
TB350	33	Trynet. Boltenia, flatfish and sea stars.

APPENDIX C

(continued)

Station	Haul Number	Remarks
TB250	34	Trynet. Same as above.
TB330	35	Trynet. Flatfish including one halibut and sea stars.
TB320	36	Rock dredge. Pea gravel, black sand. A few flatfish and sea stars.
TB216	37	Trynet. Sea stars and a few flatfish.
TB329	38	Rock dredge. Mud, stones. A few sea stars and shrimp.
TB329	39	Trynet. No substrate. Many bumpy shrimp, a few flatfish.
TB429	40	Trynet. Many yellowfin sole, sea stars, shrimp.
TB431	41	Trynet. Flatfish and sea stars.
TB540	42	Trynet. Boltenia, flatfish, sea stars.
KB240	43	Trynet. Flatfish and sea stars.
KB2*8	44	Trynet. Numerous small flatfish and sea stars.
KB2*1	45	Rock dredge. Rocks. Sea stars, shrimp.
KB2*4	46	Rock dredge. Cobble.
KB2*4	47	Rock dredge. Cobble. Polychaete tubes and first instar red king crabs, sea urchin, Pagurus beringanus.
KB2*4	48	Rock dredge. Cobble and rock. Polychaete tubes, first instar red king crabs, sea urchins. P. beringanus.
KB2*4	49	Rock dredge. Rocks (10-30 cm dia.). Some polychaete tubes, sea urchins, red king crabs.
KB2*4	50	Rock dredge. Rocks. Same as above.

APPENDIX C

(continued)

Station	Haul Number	Remarks
KB2*4	51	Rock dredge. Rocks. Same as above.
KB2*4	52	Rock dredge. Rocks. Same as above.
BB760	53	Trynet. Basket stars, sand dollars, flatfish, Boltenia.
BB770	54	Trynet. Huge haul of sand dollars, small flatfishes, red king crabs, Tanner crabs.
PM010	55	Trynet (MonArk launch). One large rock, sea stars, sea urchin.
PM010	56	Trynet. Large rocks. Red king crab, sea stars, sea urchins.
PM010	57	Trynet. Black sand. Shrimp, some fish.

APPENDIX D:

GUT CONTENT ANALYSIS FIELD NOTES

APPENDIX D

GUT CONTENT ANALYSIS FIELD NOTES

Station	Haul Number	Fish Species	Size (mm)	Gut Contents
Cruise 83-3 (June):				
IL150	03	Pacific cod	large	Euphausiids, 1 sandlance(?), gorp
IL130	04	Rock sole		Small, yellow heart urchin tests; solitary ascidians
		Yellowfin sole		Same as above
		Yellow' Irish lord	1 arge	Euphausiids and sandlance
PM320	15	Plain sculpin		l yellowfin sole, 1 crangonid
		Plain sculpin		1 small flatfish, gorp. (roundworms)
		Plain sculpin		Well-digested fish remains
		Sandfish	201	140 mm walleye pollock
		Pacific cod	300	Black pebbles, crustaceans
		Pacific cod	215	Crangonids, pebbles (ful 1 gut)
		Pacific cod	215	Euphausi ids (full gut)
		Pacific cod	140	Euphausiids (full gut)
		Pacific cod	140	Euphausiids (full gut)
		Pacific cod	140	Empty
		Walleye pollock	500	Pollock (100 inn), crangonids
		Walleye pollock	130	Euphausiids
		Walleye pollock	120	Euphausiids
		Walleye pollock	120	Euphausiids
		Rock sole	230	1 sand dollar, crustaceans (euphausiids), fish remains (semi-ful 1 stomach)
		Rock sole	370	Crustaceans (almost empty)
		Rock sole	300	Euphausi ids (ful 1)

APPENDIX D

(continued)

Station	Haul Number	Fish Species	Size (mm)	Gut Contents
		Yellowfin sole	230	Brown ascidian (?) (full)
		Yellowfin sole	200	Euphausiids (ful 1)
PM370	18	Rock sole	410	Spisula siphons, about 1 cm diameter
		Yellowfin sole	300	Whole Spisula, up to 3 cm long
		Yellowfin sole		Bivalves (Spisula?) 1-2 mm long
		Flathead sole	300	1 moon snail, 1 hermit crab
PM670	19	Rock sole		Clams, whole and broken
PM650	20	Plain sculpin	400+	Empty
		Plain sculpin	400+	Fish flesh, one Crangon
PM730/ PM620	21/22	Alaska plaice		Empty
		Alaska plaice		Empty
		Alaska plaice	250	Clam siphons (Siliqua?)
		Longhead dab	120	Gorp, polychaetes(?), grit/ dirt
		Yellowfin sole	140-280	All with evidence of clams, broken and whole shells
PM820	23	Starry flounder		Mytilus
PM950	27	Pacific cod	760	3 flatfish, one sea onion (Boltenia ovifera), euphausiids and gor p
		Pacific cod	530	Euphausiids, 3 rocks
		Pacific cod	630	Fish flesh, a 370 mm long vertebral column, euphau-siids, king crab leg, rock, clam
		Aleutian skate		Sandlance, crangonids
PM930	28	Hal ibut	430	2 sandlance, 1 flatfish

APPENDIX D

(continued)

Station	Haul Number	Fish Species	Size (m)	Gut Contents
PM920	29	Yellowfin sole	100	Brittle star rays, clam siphon tips
PH220	32	Walleye pollock	470	Euphausiids
TB450	78	Pacific cod (several)		Large pagurid claws, squid shells(?), polychaetes, euphausiids, sipunculids(?)
Cruise 83-5 (September):				
PM650	13	Plain sculpin	457	One jellyfish
PM920	20	Pacific cod	455	Sea onion, fish flesh, rocks, shells
PH120	27	Pacific cod	254	Empty
		Yellowfin sole	356	Empty
		Rock sole	250	Empty
		Plain sculpin	455	Empty
PH350	26	Yellowfin sole	356	Two Oregonia gracilis
		Pacific cod	483	Gorp, gravel
KB250	31	Yellowfin sole	315	Empty
		Yellowfin sole	175	Crustacean parts
		Rock sole	380	Bivalve shell fragments, sand, gorp
		Rock sole	250	One euphausiid, polychaetes, gammarid, amphipods, sand
TB330	35	Hal ibut		Pagurus ochotensis, Eramacrus isenbeckii
		Yellowfin sole	310	One sandlance, one holothurian

APPENDIX D

(continued)

Station	Haul Number	Fish Species	Size (mm)	Gut Contents
		Yellowfin sole	290	Empty
		Rock sole	370	Empty
TB431	41	Plain sculpin	350	Six flatfishes, one crab (*Telmesis*), three *Gymnocanthus*, gravel, gorp
TB429	40	Pacific cod	550	Full gut was 1/3 rocks (up to 25 mm diameter); crab parts (Atelecyclid); two very digested fish (flatfish?)

APPENDIX E:

MULTIPLE LINEAR REGRESSION MODELS BY RED KING CRAB AGE AND CRUISE

APPENDIX E

MULTIPLE LINEAR REGRESSION MODELS BY RED KING CRAB AGE AND CRUISE[(a)]

Number of Variables in Model	r^2	Variable
DEPENDENT VARIABLE: YOUNG-OF-THE-YEAR CRAB		
Cruise 83-1 (April-May) (n=31):		
1	0.0074	Shrimps
1	0.0088	Sea onion
1	0.0205	Depth
1	0.2851	Bryozoan
1	0.7144	Sea star
2	0.7178	Sea star, salinity
2	0.7182	Bryozoan, sea star
2	0.7241	Sea star, sponge
2	0.7294	Roundfishes, sea star
2	0.7298	Sea star, gravel
3	0.7338	Sea star, sea urchin, gravel
3	0.7378	Roundfishes, sea star, depth
3	0.7385	Roundfishes, sea star, salinity
3	0.7419	Roundfishes, sea star, sponge
3	0.7524	Roundfishes, sea star, gravel
4	0.7535	Flatfishes, roundfishes, sea star, gravel
4	0.7537	Roundfishes, sea star, worms, gravel
4	0.7548	Bryozoan, roundfishes, sea star, gravel
4	0.7562	Roundfishes, sea star, sponge, gravel
4	0.7563	Roundfishes, sea star, sea urchin, gravel
5	0.7577	Roundfishes, sea star, sponge, depth, gravel
5	0.7579	Bryozoan, roundfishes, sea star, sponge, gravel
5	0.7579	Roundfishes, sea star, sea urchin, worms, gravel
5	0.7586	Bryozoan, roundfishes, sea star, sea urchin, gravel
5	0.7661	Roundfishes, sea star, sea urchin, sponge, gravel
Cruise 83-3 (June) (n=47):		
1	0.0125	Depth
1	0.0281	Roundfishes
1	0.0338	Flatfishes
1	0.0578	Bryozoan
1	0.4859	Sea urchin

APPENDIX E

(continued)

Number of Variables in Model	r^2	Variable
2	0.4987	Sea urchin, gravel
2	0.5011	Sea urchin, sponge
2	0.5031	Roundfishes, sea urchin
2	0.5036	Flatfishes, sea urchin
2	0.5185	Bryozoan, sea urchin
3	0.5263	Flatfishes, roundfishes, sea urchin
3	0.5308	Bryozoan, flatfishes, sea urchin
3	0.5339	Bryozoan, sea urchin, gravel
3	0.5361	Bryozoan, sea urchin, sponge
3	0.5390	Bryozoan, roundfishes, sea urchin
4	0.5460	Bryozoan, flatfishes, sea urchin, gravel
4	0.5474	Bryozoan, sea urchin, sponge, gravel
4	0.5491	Bryozoan, flatfishes, sea urchin, sponge
4	0.5556	Bryozoan, roundfishes, sea urchin, sponge
4	0.5559	Bryozoan, flatfishes, roundfishes, sea urchin
5	0.5602	Bryozoan, flatfishes, sea urchin, sponge, gravel
5	0.5603	Bryozoan, roundfishes, sea urchin, sponge, salinity
5	0.5628	Bryozoan, roundfishes, sea urchin, shrimps, sponge
5	0.5633	Bryozoan, flatfishes, round fishes, sea urchin, shrimps
5	0.5733	Bryozoan, flatfishes, roundfishes, sea urchin, worms

Cruise 83-5 (September) (n=36):

1	0.0712	Depth
1	0.3709	Gravel
1	0.7418	Worms
1	0.8211	Salinity
1	0.9982	Sea urchin
2	0.9982	Roundfishes, sea urchin
‘ 2	0.9982	Sea star, sea urchin
2	0.9982	Bryozoan, sea urchin
2	0,9985	Sea urchin, gravel
2	0.9995	Sea urchin, shrimps

APPENDIX E

(continued)

Number of Variables in Model	r^2	Variable
3	009995	Sea urchin, shrimps, salinity
3	0.9995	Sea urchin, shrimps, worms
3	0.9995	Flatfishes, sea urchin, shrimps
3	0.9996	Sea star, sea urchin, shrimps
3	0.9996	Bryozoan, sea urchin, shrimps
4	0.9996	Bryozoan, sea urchin, shrimps, salinity
4	0.9996	Bryozoan, flatfishes, sea urchin, shrimps
4	0.9996	Bryozoan, sea urchin, shrimps, worms
4	0.9997	Bryozoan, sea star, sea urchin, shrimps
4	0.9997	Flatfishes, sea star, sea urchin, shrimps
5	0.9997	Flatfishes, sea star, sea urchin, shrimps, worms
5	0.9997	Flatfishes, sea onion, sea star, sea urchin, shrimps
5	0.9997	Flatfishes, roundfishes, sea star, sea urchin, shrimps
5	0.9997	Flatfishes, sea star, sea urchin, shrimps, depth
5	0.9998	Bryozoan, flatfishes, sea star, sea urchin, shrimps

DEPENDENT VARIABLE: 1-2 AGE CRAB

Cruise 83-1 (April-May) (n=31):

1	0.0540	Depth
1	0.1978	Salinity
1	0.3135	Shrimps
1	0.3442	Gravel
1	0.9530	Sea urchin
2	0.9538	Sea star, sea urchin
2	0.9540	Sea urchin, sponge
2	0.9584	Sea urchin, gravel
2	0.9680	Sea urchin, shrimps
2	0.9753	Sea urchin, salinity
3	0.9757	Sea star, sea urchin, salinity
3	0.9760	Roundfishes, sea urchin, salinity

Number of Variables in Model	r2	Variable
Cruise 83-5 (September) (n=36): (continued)		
3	0.9995	Sea urchin, shrimps, salinity
3	0.9995	Sea urchin, shrimps, worms
3	0.9995	Flatfishes, sea urchin, shrimps
3	0.9996	Sea star, sea urchin, shrimps
3	0.9996	Bryozoan, sea urchin, shrimps
4	0.9996	Bryozoan, sea urchin, shrimps, salinity
4	0.9996	Bryozoan, flatfishes, sea urchin, shrimps
4	0.9996	Bryozoan, sea urchin, shrimps, worms
4	0.9997	Bryozoan, sea star, sea urchin, shrimps
4	0.9997	Flatfishes, sea star, sea urchin, shrimps
5	0.9997	Flatfishes, sea star, sea urchin, shrimps, worms
5	0.9997	Flatfishes, sea onion, sea star, sea urchin, shrimps
5	0.9997	Flatfishes, roundfishes, sea star, sea urchin, shrimps
5	0.9997	Flatfishes, sea star, sea urchin, shrimps, depth
5	0.9998	Bryozoan, flatfishes, sea star, sea urchin, shrimps
IIEPENDENT VARIABLE: 1-2 AGE CRAB		
Cruise 83-1 (April-flay) (n=31):		
1	0.0540	Depth
1	0.1978	Salinity
1	0.3135	Shrimps
1	0.3442	Gravel
1	0.9530	Sea urchin
2	0.9538	Sea star, sea urchin
2	0.9540	Sea urchin, sponge
2	0.9584	Sea urchin, gravel
2	0.9680	Sea urchin, shrimps
2	0.9753	Sea urchin, salinity
3	0.9757	Sea star, sea urchin, salinity
3	0.9760	Roundfishes, sea urchin, salinity

APPENDIX E

(continued)

Number of Variables in Model	r2	Variable
3	0.9762	Sea urchin, shrimps, salinity
3	0.9684	Sea onion, sea urchin, salinity
3	0.9815	Sea urchin, depth, salinity
4	0.9818	Sea urchin, sponge, depth, salinity
4	0.9819	Bryozoan, sea urchin, depth, salinity
4	0.9824	Sea urchin, dkepth, salinity, gravel
4	0.9824	Sea urchin, shrimps, depth, salinity
4	0.9826	Sea onion, sea urchin, depth, salinity
5	0.9829	Bryozoan, sea urchin, depth, salinity, gravel
5	0.9831	Bryozoan, sea onion, sea urchin, depth, salinity
5	0.9833	Sea onion, sea urchin, shrimps, depth,"salinlty
5	0.9835	Sea onion, sea urchin, depth, salinity, gravel
5	0.9844	Sea urchin, shrimps, depth, salinity, gravel

Cruise 83-3 (June) (n=47):

1	0.0039	Bryozoan
1	0.0046	Sea star
1	0.0051	Gravel
1	0.0077	Flatfishes
1	0.0259	Depth
2	0.0348	Roundfishes, depth
2	0.0385	Depth, salinity
2	0.0395	Depth, temperature
2	0.0451	Flatfishes, depth
2	0.0480	Depth, gravel
3	0.0541	Flatfishes, sea star, depth
3	0.0581	Depth, salinity, gravel
3	0.0591	Depth, temperature, gravel
3	0.0600	Sea star, depth, gravel
3	0.0726	Flatfishes, depth, gravel
4	0.0755	Flatfishes, depth, temperature, gravel
4	0.0772	Sea star, depth, salinity, gravel
4	0.0822	Flatfishes, sea urchin, depth, gravel
4	0.0825	Bryozoan, flatfishes, depth, gravel
4	0.0864	Flatfishes, sea star, depth, gravel

APPENDIX E

(continued)

Number of Variables in Model	r2	Variable
5	0.0911	Bryozoan, flatfishes, sea urchin, depth, gravel
5	0.9815	Flatfishes, sea star, depth, temperature, gravel
5	0.0926	Flatfishes, sea star, depth, salinity. gravel
5	0.0962	Bryozoan, flatfishes, sea star, depth, gravel
5	0.0980	Flatfishes, sea star, sea urchin, depth, gravel
Cruise 83-5 (September) (n=36):		
1	0.0563	Temperature
1	0.0768	Salinity
1	0.1082	Sea urchin
1	0.5498	Worms
2	0.5536	Shrimps, worms
2	0.5597	Sponge, worms
2	0.5859	Worms, gravel
2	0.7611	Worms, salinity
2	0.9239	Sea urchin, worms
3	0.9255	Roundfishes, sea urchin, worms
3	0.9260	Sea urchin, worms, temperature
3	0.9265	Bryozoan, sea urchin, worms
3	0.9308	Sea urchin, worms, gravel
3	0.9308	Sea urchin, worms, depth
4	0.9325	Roundfishes, sea urchin, worms, gravel
4	0.9329	Bryozoan, sea urchin worms, depth
4	0.9335	Bryozoan, sea urchin worms, gravel
4	0.9335	Sea urchin, worms, depth, gravel
4	0.9364	Sea urchin, sponge, worms, gravel
5	0.9373	Sea urchin, sponge, worms, salinity, gravel
5	0.9374	Sea urchin, sponge, worms, temperature, gravel
5	0.9386	Sea urchin, sponge, worms, depth, gravel
5	0.9388	Bryozoan, sea urchin, sponge, worms, gravel
5	0.9426	Sea urchin, shrimps, sponge, worms, gravel

Number of Variables in Model	r^2	Variable
DEPENDENT VARIABLE: 2+ and3 AGE CRAB		
Cruise 83-1 (April-May) (n=31):		
1	0.0397	Flatfishes
1	0.0793	Salinity
1	0.1510	Gravel
1	0.1692	Sponge
1	0.5699	Sea urchin
2	0.5814	Sea urchin, shrimps
2	0.5905	Sea urchin, gravel
2	0.6063	Sea urchin, salinity
2	0.6123	Sea urchin, temperature
2	0.6324	Sea star, sea urchin
3	0.6514	Flatfishes, sea urchin, temperature
3	0.6527	Sea star, sea urchin, shrimps
3	0.6638	Sea star, sea urchin, salinity
3	0.6682	Sea star, sea urchin, temperature
3	0.6701	Bryozoan, sea star, sea urchin
4	0.6923	Bryozoan, sea star, sea urchin, shrimps
4	0.6974	Sea star, sea urchin, salinity, temperature
4	0.7038	Bryozoan, sea star, sea urchin, salinity
4	0.7076	Flatfishes, sea star, sea urchin. temperature
4	0.7085	Bryozoan, sea star, sea urchin, temperature
5	0.7284	Flatfishes, sea star, sea urchin, temp.. gravel
5	0.7298	Bryozoan, sea star, sea urchin, depth, temp.
5	0.7362	Flatfishes, sea star, sea urchin, salinity, temp.
5	0.7399	Bryozoan, sea star, sea urchin, salinity, temp.
5	0.7469	Bryozoan, flatfishes, sea star, sea urchin, temp.
Cruise 83-3 (June) (n=47):		
1	0.0206	Temperature
1	0.0248	Salinity
1	0.0538	Sponge
1	0.0691	Roundfishes
1	0.1352	Sea star

Number of Variables in Model	r2	Variable
2	0.1468	Sea star, temperature
2	0.1568	Sea star, depth
2	0.1638	Roundfishes, shrimps
2	0.1919	Roundfishes, sea star
2	0.1926	Sea star, sponge
3	0.2121	Roundfishes, sea star, temperature
3	0.2310	Roundfishes, sea star, depth
3	0.2424	Roundfishes, sea star, shrimps
3	0.2460	Roundfishes, sea star, gravel
3	0.2513	Roundfishes, sea star, sponge
4	0.2711	Roundfishes, sea star, sponge, depth
4	0.2783	Roundfishes, sea star, shrimps, gravel
4	0.2788	Roundfishes, sea star, shrimps, depth
4	0.2897	Roundfishes, sea star, sponge, gravel
4	0.2942	Roundfishes, sea star, shrimps, sponge
5	0.3011	Roundfishes, sea star, sea urchin, sponge, gravel
5	0.3076	Roundfishes, sea star, shrimps, sponge, temp.
5	0.3083	Roundfishes, sea star, sea urchin, shrimps, sponge
5	0.3132	Roundfishes, sea star, shrimps, sponge, depth
5	0.3190	Roundfishes, sea star, shrimps, sponge, gravel

Cruise 83-5 (September) (n=36):

No data

DEPENDENT VARIABLE: 3+ AGE CRAB

Cruise 83-1 (April-May) (n=31):

1	0.0473	Flatfishes
1	0.0507	Roundfishes
1	0.0750	Gravel
1	0.2416	Sponge
1	0.4224	Sea urchin

APPENDIX E

(continued)

Number of Variables in Model	r2	Variable
2	0.4540	Sea urchin, shrimps
2	0.4640	Sea urchin, gravel
2	0.4826	Sea urchin, depth
2	0.5031	Sea urchin, salinity
2	0.5157	Roundfishes, sea urchin
3	0.5339	Roundfishes, sea urchin, shrimps
3	0.5357	Roundifshes, sea urchin, temperature
3	0.5427	Roundfishes, sea urchin, gravel
3	0.5461	Roundfishes, sea urchin, sponge
3	0.5645	Roundfishes, sea urchin, salinity
4	0.5743	Roundfishes, sea star, sea urchin, salinity
4	0.5755	Roundfishes, sea urchin, sponge, salinity
4	0.5755	Flatfishes, roundfishes, sea urchin, temperature
4	0.5782	Roundfishes, sea urchin, salinity, temperature
4	0.5806	Flatfishes, roundfishes, sea urchin, salinity
5	0.5917	Flatfishes, roundfishes, sea urchin, worms, temp.
5	0.5926	Roundfishes, sea urchin, sponge, temp., gravel
5	0.6042	Flatfishes, roundfishes, sea urchin, sponge, temp.
5	0.6067	Flatfishes, roundfishes, sea urchin, temperature, gravel
5	0.6149	Flatfishes, roundfishes, sea urchin, salinity, temperature

Cruise 83-3 (June) (n=47):

Number of Variables in Model	r2	Variable
1	0.0111	Gravel
1	0.0380	Salinity
1	0.0477	Depth
1	0.1091	Sea onion
1	0.1289	Sponge
2	0.1409	Flatfishes, sponge
2	0.1444	Sponge, salinity
2	0.1463	Sponge, depth
2	0.1479	Sea urchin, sponge
2	0.1655	Sea onion, sponge

APPENDIX E

(continued)

Number of Variables in Model	r^2	Variable
3	0.1735	Sea onion, sponge, depth
3	0.1764	Flatfishes, sponge, salinity
3	0.1776	Sea onion, sponge, salinity
3	0.1783	Sea onion, sea urchin, sponge
3	0.1794	Flatfishes, sea onion, sponge
4	0.1923	Sea onion, sea urchin, sponge, salinity
4	0.1933	Flatfishes, sea onion, sponge, temperature
4	0.1953	Flatfishes, sea urchin, sponge, salinity
4	0.1955	Flatfishes, sea onion, sponge, depth
4	0.2103	Flatfishes, sea onion, sponge, salinity
5	0.2113	Flatfishes, sea onion, sea star, sponge, salinity
5	0.2121	Bryozoa, flatfishes, sea onion, sponge, salinity
5	0.2127	Flatfishes, roundfishes, sea onion, sponge, salinity
5	0.2143	Flatfishes, sea onion, sponge, depth, salinity
5	0.2230	Flatfishes, sea onion, sea urchin, sponge, salinity
Cruise 83-5 (September) (n=36):		
1	0.0302	Bryozoa
1	0.0330	Roundfishes
1	0.2081	Depth
1	0.2901	Temperature
1	0.3873	Sea onion
2	0.3922	Sea onion, gravel
2	0.3948	Roundfishes, sea onion
2	0.3973	Bryozoan, sea onion
2	0.4113	Sea onion, depth
2	0.5714	Sea onion, temperature
3	0.5771	Sea onion, sea star, temperature
3	0.5772	Sea onion, sea urchin, temperature
3	0.5789	Sea onion, worms, temperature
3	0.5806	Sea onion, salinity, temperature
3	0.5844	Bryozoa, sea onion, temperature

APPENDIX E

(continued)

Number of Variables in Model	r^2	Variable
4	0.5919	Bryozoan, sea onion, sea star, temperature
4	0.5939	Bryozoan, sea onion, worms, temperature
4	0.5945	Flatfishes, sea onion, sea star. temperature
4	0.5948	Bryozoan, sea onion, salinity, temperature
4	0.5984	Flatfishes, roundfishes, sea onion, temperature
5	0.6084	Flatfishes, roundfishes, sea onion, worms, temp.
5	0.6115	Flatfishes, roundfishes, sea onion, salinity, temperature
5	0.6164	Flatfishes, roundfishes, sea onion, sea star, temperature
5	0.6199	Bryozoan, flatfishes, sea onion, sea star, temp.
5	0.6212	Bryozoan, flatfishes, roundfishes, sea onion, temperature

(a) Key: See Section 2.4 for multiple linear regression model methodology

APPENDIX F:

NILE RED KING CRAB SUBSTRATE PREFERENCE TESTS

APPENDIX F

JUVENILE RED KING CRAB SUBSTRATE PREFERENCE TESTS

The following tests were conducted aboard the NOAA ship *Miller Freeman* during the June cruise (83-3). The objective was to test for substrate preference in juvenile red king crabs.

Materials

The materials used included a large fiberglass aquarium (approximately 1 m x 1m x 1m) supplied with running sea water. The aquarium was kept in a room with subdued light and covered with black plastic and wooden boards to keep out light. Crab counts were made with the use of a red-lense flashlight. Six age 1+ red king crabs were used for the tests. The carapace length and sex were determined for five of these crabs: male, 22 mm; male, 20 mm; male, 20 mm; female, 22.5 iron; and female, 16.5 mm.

Methods

Before each test, crabs were kept separated in water-filled glass containers for several hours.

Test 1: Bare Substrates. Each quarter of the aquarium bottom was covered with one substrate type, as indicated in Figure F1. At the beginning of the test, six crabs were placed on the substrates in the positions in Figure F1. The locations of crabs were observed and plotted every 15 minutes for two hours during the first run, and approximately every 30 minutes for three and one-half hours during the second run. The crabs were left in the aquarium for the 16 hours between runs. At the end of the test, the total number of crab observations tallied per quadrat were summed (Table F1) (one half crab was tallied for each of two quadrats where border were stradled by a single crab).

Test 2: Substrate and Epifaunal "Reefs". Test 2 involved the placement of an epifaunal "reef" in he center of each bottom quadrat. The reef materials included erect bryozoans attached to rocks, tube worm colonies, mussels and large barnacles. Reef positions are shown in Figure F2. Crabs were held in glass containers as for Test 1, and placed in the aquarium positions indicated in Figure F2. Crab locations were plotted six times during a six-hour period. Crab position tallies are presented in Table F2.

APPENDIX F

(continued)

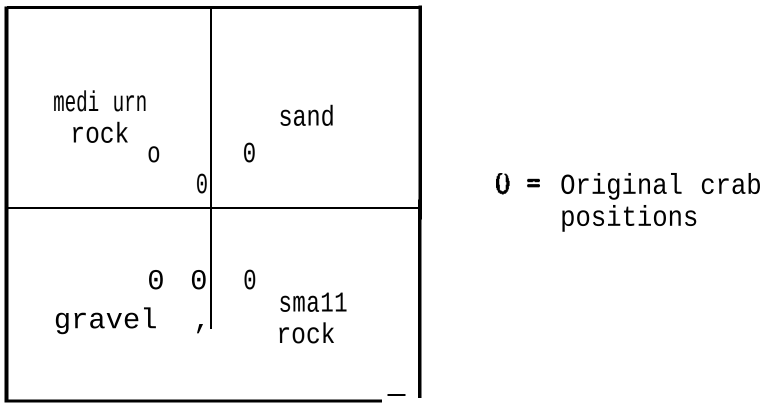

Figure F1. Substrates Used in Test 1.

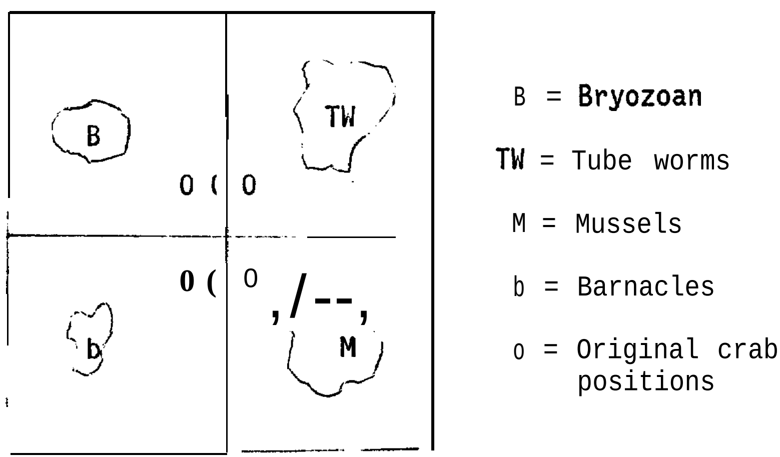

Figure F2. "Reef" Materials Used in Test 2. Substrates Are the Same as in Figure F1.

Results and Discussion

Test 1: The greatest percentage of crabs, 55 percent, was found on the medium rock substrate; the lowest percentage, 10 percent, was found on gravel. Although far from conclusive, this simple test indicates a marked preference for the largest-grained substrate.

Test 2: The greatest percentage of crabs, 40 percent, was found in the quadrat with tube worms, followed by mussels, then barnacles, then bryozoans. Crabs were observed in contact with the "reef" materials only on the tube worms. The results indicate that the epifauna present in the quadrats may have been more important to the test animals than the actual bare substrate.

General Comments

A number of variables could not be accounted for in these tests. Feeding crabs (i.e., hunger) could have been a major factor in Test 2 results. The crabs were left in the aquarium after Test 2 for observation; some were seen feeding on tube worms and scavenging for food between the mussels.

TABLE F1

RESULTS OF TEST 1

	Medium Rock	Sand	Small Rock	Gravel
Number of crabs	49.5	15.5	16	9
Percent of total	55	17	18	10

TABLE F2

RESULTS OF TEST 2

	Medium Rock	Sand	Small Rock	Gravel
Number of crabs	2.5	14.5	11.5	7.5
Percent of total	7	40	32	21